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ENGINEERING ASSESSMENT OF HYDRODYNAMICS AND JETTY SCOUR AT LITTLE RIVER INLET NORTH AND SOUTH CAROLINA

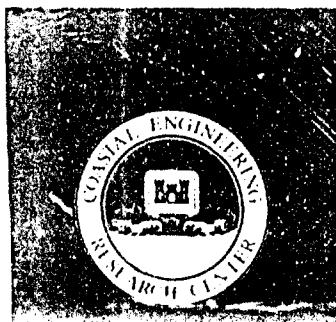
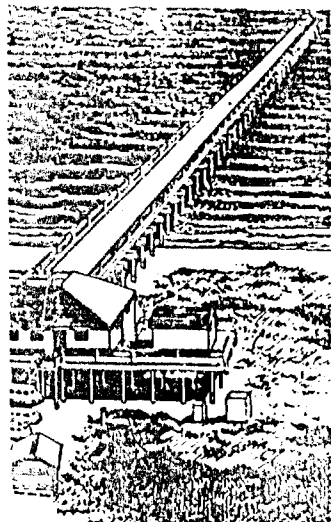
by

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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY

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13. ABSTRACT (Maximum 200 words) <p>Little River Inlet is a shallow coastal inlet located on the Atlantic Ocean along the North Carolina-South Carolina border. Construction by the US Army Engineer District, Charleston (SAC) of a dual-jetty system at Little River Inlet began in March 1981 and was completed in July 1983.</p> <p>A detailed monitoring program conducted from 1979 through 1992 has documented the performance of the Little River Inlet project. A two-phase analysis of the monitoring data and navigation project was conducted by the Coastal Engineering Research Center (CERC). The objectives of the first phase analysis were to summarize beach and nearshore response to the Little River Inlet navigation project and assist SAC in developing dredged material management plans (Chasten 1992). The second phase of analysis involved a reconnaissance-level review of the post-jetty thalweg evolution and stability, relative inlet hydrodynamics, and scour occurring at the jetty structures. This paper summarizes the second phase of the CERC study and performance of the Little River Inlet navigation project.</p>				
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PREFACE

The investigation summarized in this report was conducted by the US Army Engineer Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC) through a reimbursable study for the US Army Engineer District, Charleston (SAC). Mr. James Joslin and Mr. Millard Dowd were the SAC representatives involved in this study. Funds were provided by SAC.

Work was performed under the general supervision of Dr. Yen-hsi Chu, Chief, Engineering Applications Unit (EAU), Coastal Structures and Evaluation Branch (CSEB); Ms. Joan Pope, Chief, CSEB; Mr. Thomas W. Richardson, Chief, Engineering Development Division; Mr. Charles C. Calhoun, Jr., Assistant Director, CERC; and Dr. James R. Houston, Director, CERC.

This report was prepared by the Principal Investigator of the reimbursable study, Ms. Monica A. Chasten, EAU, CSEB, and Mr. William C. Seabergh, Wave Dynamics Division. Technical assistance with the data analysis was provided by Ms. Mary Claire Allison, Mr. Darryl Bishop, Mr. Joseph Curro III, Ms. Kelly Lanier, and Ms. Karen Pitchford, all of CSEB. Field data collection was conducted by Mr. Gene Heisselman, Mr. Fred Lutge, and Mr. Millard Dowd, all of SAC; Dr. Douglas Levin, Bryant College; and Messrs. Larry Caviness, and William Kucharski, and Ms. Chasten, all of CERC. Dr. Levin also conducted the side scan sonar analysis and data interpretation. Mr. Bishop and Ms. Pitchford, Janie Daughtry, Jennifer Irish, and Leona Patty provided assistance in preparing the manuscript and figures. Technical reviewers of the report were Dr. Yen-hsi Chu and Mr. Jeff Lillycrop. The assistance of Mr. Dowd, SAC, throughout the study is greatly appreciated.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
miles	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
tons (2,000 pounds mass)	907.1847	kilograms

ENGINEERING ASSESSMENT OF HYDRODYNAMICS AND JETTY SCOUR AT
LITTLE RIVER INLET, NORTH AND SOUTH CAROLINA

PART I: INTRODUCTION

Purpose

1. The Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC) conducted an analysis for the U.S. Army Engineer District, Charleston (SAC) of post-jetty evolution and hydrodynamics of the Little River Inlet channel, and scour occurring at the jetty structures. The investigation described herein is the second phase of a two-part effort which examined performance of the Little River Inlet navigation project. The first phase evaluated beach and nearshore response to the project and provided recommendations on dredged material disposal options (Chasten 1992). The first phase study concluded that migration of the inlet thalweg and scour at the east jetty tip and along the length of the west jetty were important project concerns relative to potential dredging and nourishment operations at Little River Inlet.

2. The objectives of this analysis were to perform a reconnaissance level review of inlet channel stability and hydrodynamics and to evaluate scour occurring at the jetty structures. Recommendations then were developed for a maintenance and monitoring plan within Little River Inlet.

Background

3. Little River Inlet is located on the Atlantic Ocean along the North Carolina-South Carolina border (Figure 1), approximately 23^o miles northeast of Myrtle Beach, South Carolina. The inlet is the ocean entrance to the towns of Little River and Calabash, the Atlantic Intracoastal Waterway (AIWW), and several tidal streams. The back bay serves as a safe coastal harbor for many private, recreational, and commercial fishing boats (US Army Engineer District

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5.

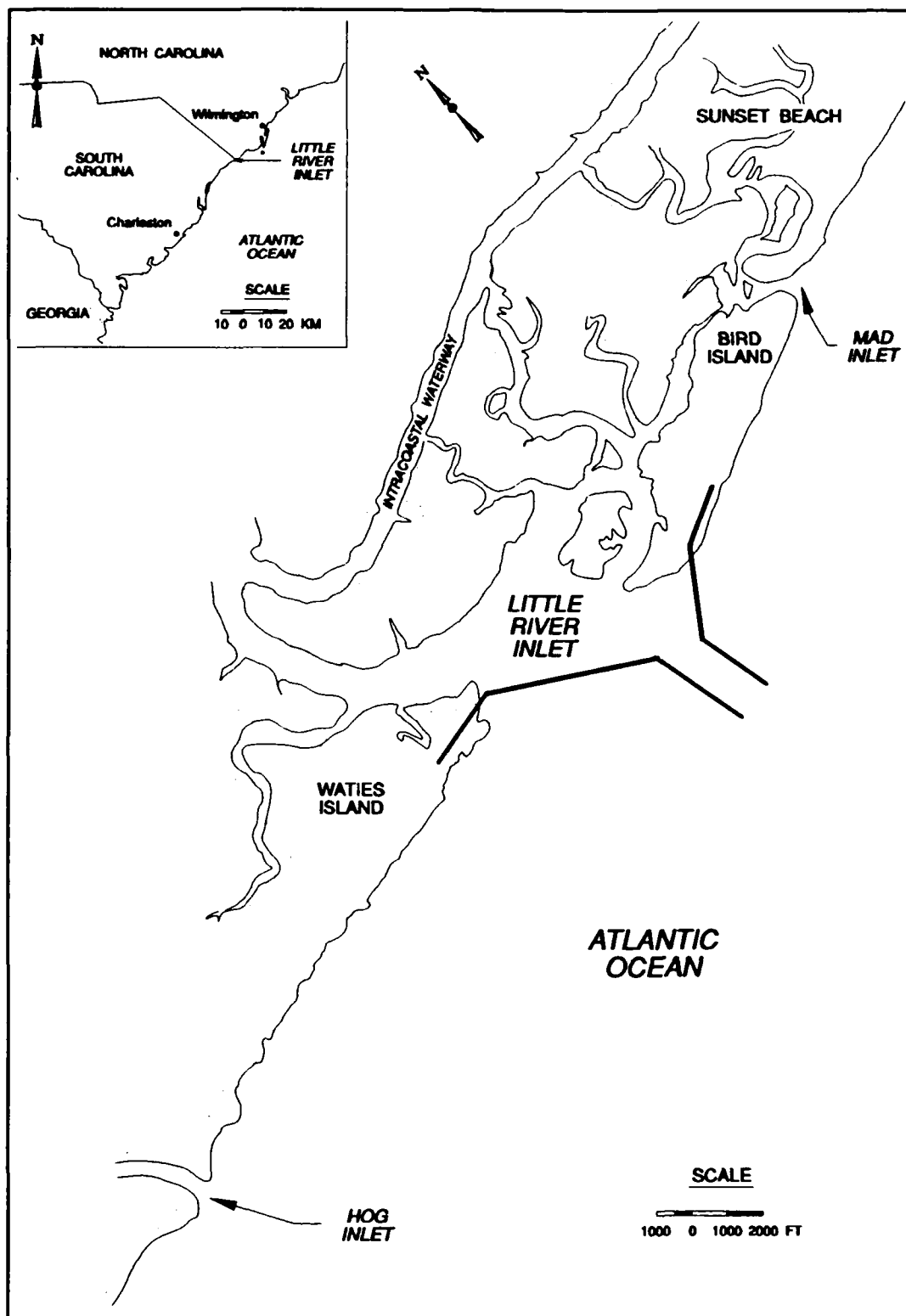


Figure 1. Study area location map

(USAED), Charleston 1977). Little River Inlet is the only navigable ocean outlet from the AIWW between Shallotte Inlet, NC and Georgetown, SC, a distance of 68 miles.

4. The inlet is part of the "Grand Strand," an area along South Carolina's northeastern shore consisting of 60 miles of resort beaches. Bird Island, an undeveloped privately-owned area lies to the northeast of the inlet. To the southwest is Waties Island, also privately owned and undeveloped.

5. Historically, frequent shifting and migration of the barred channel and extensive sand shoals made the inlet extremely dangerous for navigation (Seabergh and Lane 1977). As a result, a project for improvement and stabilization of Little River Inlet was authorized by Congress in 1972 under Section 201 of the Flood Control Act of 1965. Construction of a dual jetty system at the inlet began in March 1981 and was completed in July 1983.

Physical Setting

6. Little River Inlet is located within a geomorphic coastal zone termed the arcuate strand (Brown 1977). Landward, the strand abuts a mid-Pleistocene beach ridge deposit (Ward and Knowles 1987). The coastline is relatively straight and interrupted by few tidal inlets.

7. Tidal inlet morphology along this portion of the Carolina coast is characterized as mixed-energy (Hubbard, Oertel, and Nummedal 1979) trending toward tide domination (Davis and Hayes 1984). In a mixed-energy inlet, shoals located near the throat are separated by channels of variable depth. Prior to stabilization, shoals at Little River Inlet were located slightly seaward of the inlet throat.

8. The mean tidal range for this region is 5.0 ft. This range lies within the overlap between the upper end of the microtidal envelope and the beginning of the mesotidal range (Davies 1964). The average significant wave height for the vicinity is approximately 1.8 ft with a mean wave period of 5.1 sec (Jensen 1983). Little River Inlet is somewhat protected from waves out of the northeast by Frying Pan Shoals at Cape Fear, NC.

9. Little River Inlet is connected with a marsh area and the AIWW, which in turn is joined to the Waccamaw River. Freshwater inflow from this source was estimated to average 1,200 cfs, or 53.6 million cu ft per tidal

cycle (based on correlation with United States Geological Survey gage data and prototype measurements taken in April 1974). Based on observations made in April 1974, the pre-project tidal prism was 505 million cu ft for a mean ocean tide range of 5.0 ft over a 12.42-hr tidal cycle including a freshwater inflow of 1,200 cfs (Seabergh and Lane 1977).

10. Longshore sediment transport in the vicinity of Little River Inlet has been difficult to define, both in quantity and direction. Chasten (1992) presents various transport analyses which have been conducted for the study area and concludes that longshore transport is variable but slightly dominant to the northeast. Attempts to quantify longshore transport in the vicinity of Little River Inlet have been inconclusive.

Project Description

11. The authorized inlet stabilization project provides for an entrance channel 12-ft deep, 3,200-ft long, and 300-ft wide across the ocean bar, and an inner channel, 10-ft deep, 9,050-ft long, and 90-ft wide from the entrance channel to the AIWW. The channel is stabilized by two rubble mound jetties, with sand transition dikes connecting the structures to the shore (Figures 2 and 3). A low weir section was built into each jetty, and then subsequently covered with armor stone.

12. Optimum design of the navigation project was determined through the use of a fixed-bed hydraulic model study (Seabergh and Lane 1977). This study examined alignment, length, and spacing of the jetties; weir sections; current patterns and magnitudes; sediment movement patterns; effects on the tidal prism; and effects on bay salinities.

13. The two jetties are of typical quarystone, rubble-mound construction. Seven various sizes of stone weighing between 2.5 lb and 8 tons were used to construct the jetties. The east jetty is approximately 3,300-ft long, and the west jetty is approximately 3,800-ft long. Both jetties include a sand dike to anchor the structure to shore, a weir, and a sand-tight section joining the weir to the sand dike.

14. The hydraulic model study determined that a 1,300-ft weir section at elevation +2.4 ft MLW backed by deposition basins would be the most feasible plan for both jetties. As constructed, this 1,300-ft section was divided into a 650-ft sand-tight section connected to the shore and a 650-ft

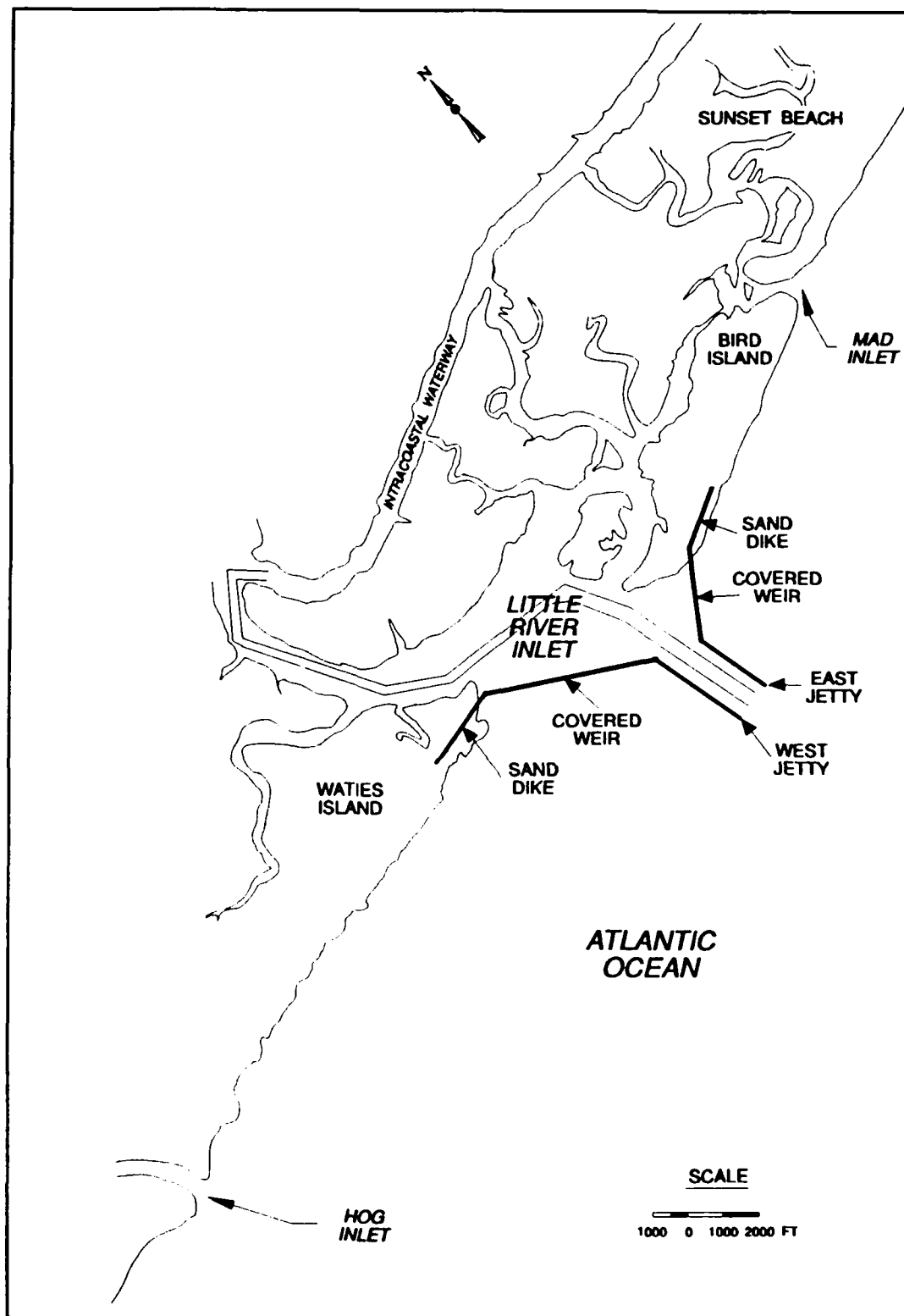


Figure 2. Little River Inlet navigation project and vicinity

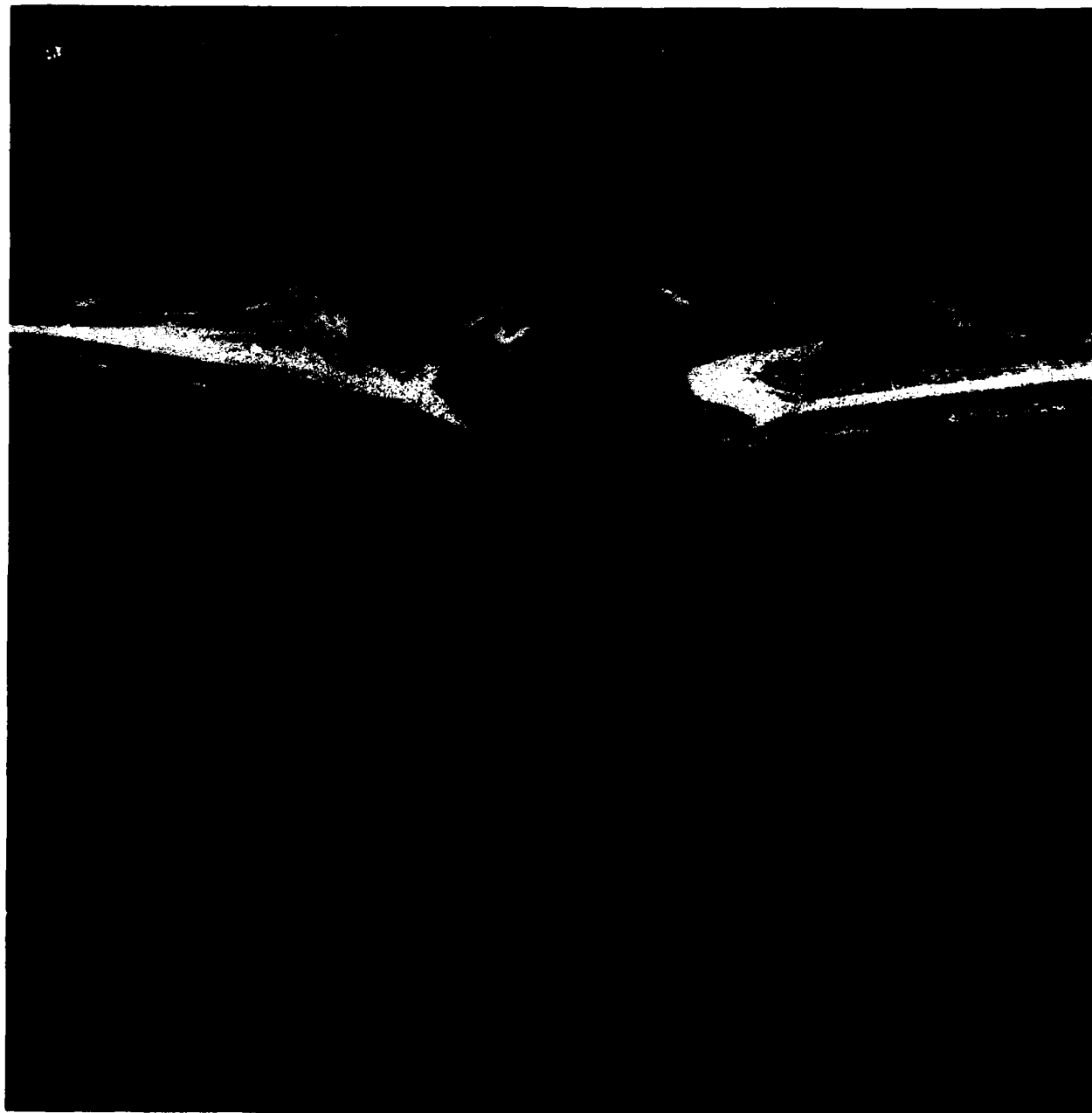


Figure 3. Aerial photography of Little River Inlet: March 1988

weir, in order to provide more control of sand overtopping the weir. However, since the longshore transport direction was considered variable, the weirs were subsequently covered with armor units to an elevation of +8 ft MLW, with the intention of removing the stones if required in the future. The deposition basins were never dredged.

Construction and Dredging History

15. Construction of the east jetty began in July 1981 and was completed in June 1982. Initial dredging of the entrance channel to a 300-ft width and 12-ft depth was performed between June and July 1982. This dredging effort removed 513,000 cu yd of material from the channel, which was subsequently used to construct the west sand dike. Stone placement for the west jetty began in June 1982 and was finished in early June 1983.

16. Little River Inlet has been dredged only once since the initial dredging of the channel. This dredging effort was completed between December 1983 and February 1984. Total volume removed from the entrance and inner channels was 264,000 cu yd. Most of this material was placed adjacent to the inner side of the west jetty due to channel migration toward this jetty.

Monitoring Program

17. The SAC began collecting pre-project baseline data at the Little River Inlet project in 1979. A formal monitoring program was initiated by SAC and CERC in 1981 and has continued through the present, albeit with a reduced scope since 1986. The primary objectives of this program were to evaluate the performance of the jetty system and document its effects on adjacent shorelines. The monitoring program consisted of beach profile surveys, inlet hydrographic surveys, aerial photography collection, structural surveys, site inspections, and Littoral Environment Observation data collection.

Summary of Phase I Analysis

18. An analysis of the monitoring data collected between 1979 and 1989 was conducted to evaluate beach and nearshore response to the Little River Inlet navigation project (Chasten 1992). This analysis concluded that the

Little River Inlet project has not had significant detrimental impacts on adjacent shorelines, and the interruption of longshore sediment transport along the Waties/Bird Island coastal cell has been minimal. The two areas showing significant accretion were the fillet west of the jetties and the western portion of Bird Island just inside the jetties. The primary source of material for both areas was the migration and attachment of portions of the pre-jetty ebb tidal delta. Chasten (1992) also concluded that periodic erosional and accretional trends on the western end of Waties Island were evident prior to construction of the Little River Inlet jetties, and are primarily due to the dynamic nature of Hog Inlet. Various dredged material disposal options were evaluated, and continued project monitoring was recommended along with further examination of channel migration and scour occurring at the jetty structures (Phase II).

PART II: CHANNEL MIGRATION AND JETTY SCOUR

19. Since the jetties were constructed, the channel has migrated and meandered relative to the constructed project channel (Figure 4). Scour holes have formed along the west jetty and at both the east and west jetty tips. Initially, maximum depths of 20 to 25 ft along the west jetty occurred at the bend or "dog-leg" of the structure. Scour along the west jetty has more recently been documented to run within 50 ft of the structure toe to a depth of 25 ft MLW for approximately 2,000 ft (USAED, Charleston 1990). Presently, depths at the west jetty tip range between 25 and 30 ft. Maximum scour hole depths at the tip of the east jetty are approximately 30 to 32 ft MLW (based on 1991 bathymetric surveys).

20. A naturally deep area, on the order of 25 to 30 ft, exists farther back in the inlet throat near the inlet-facing shoreline of Bird Island (see Figure 4). This hole existed prior to jetty construction and appears to be due to the confluence of the two channels that feed into the main inlet channel. Where flow channels converge, a deep hole one-third to three times greater than the general depth of the channel trough can occur downstream of the convergence (Price 1963; Kjerfve, Shao, and Staper 1979). The hole has continued to move slightly seaward since project construction.

21. Bathymetric maps show that scour at the structures began to develop soon after jetty construction was completed. By October 1983, depths of approximately 25 to 28 ft MLW were evident at both the west jetty bend and the east jetty tip. The SAC attempted to mitigate the scour by placing material from the December 1983 dredging of the Little River Inlet channel into the scour areas; however, these efforts proved to be only a temporary solution and the deepening trends continued.

22. The SAC has been monitoring erosion and slope steepening at these scour locations in order to evaluate the condition of and potential risk to the structures. A stability analysis was completed for the west jetty in February 1990 (USAED, Charleston 1990). Results indicated an average existing slope of 1 vertical on 2.5 horizontal, with a computed factor of safety of 1.7. The required factor of safety is 1.5; corresponding to a minimum acceptable slope of 1 vertical on 2 horizontal. This study concluded that a continued increase in erosion toward the west jetty would require remedial measures to insure the structure's integrity.

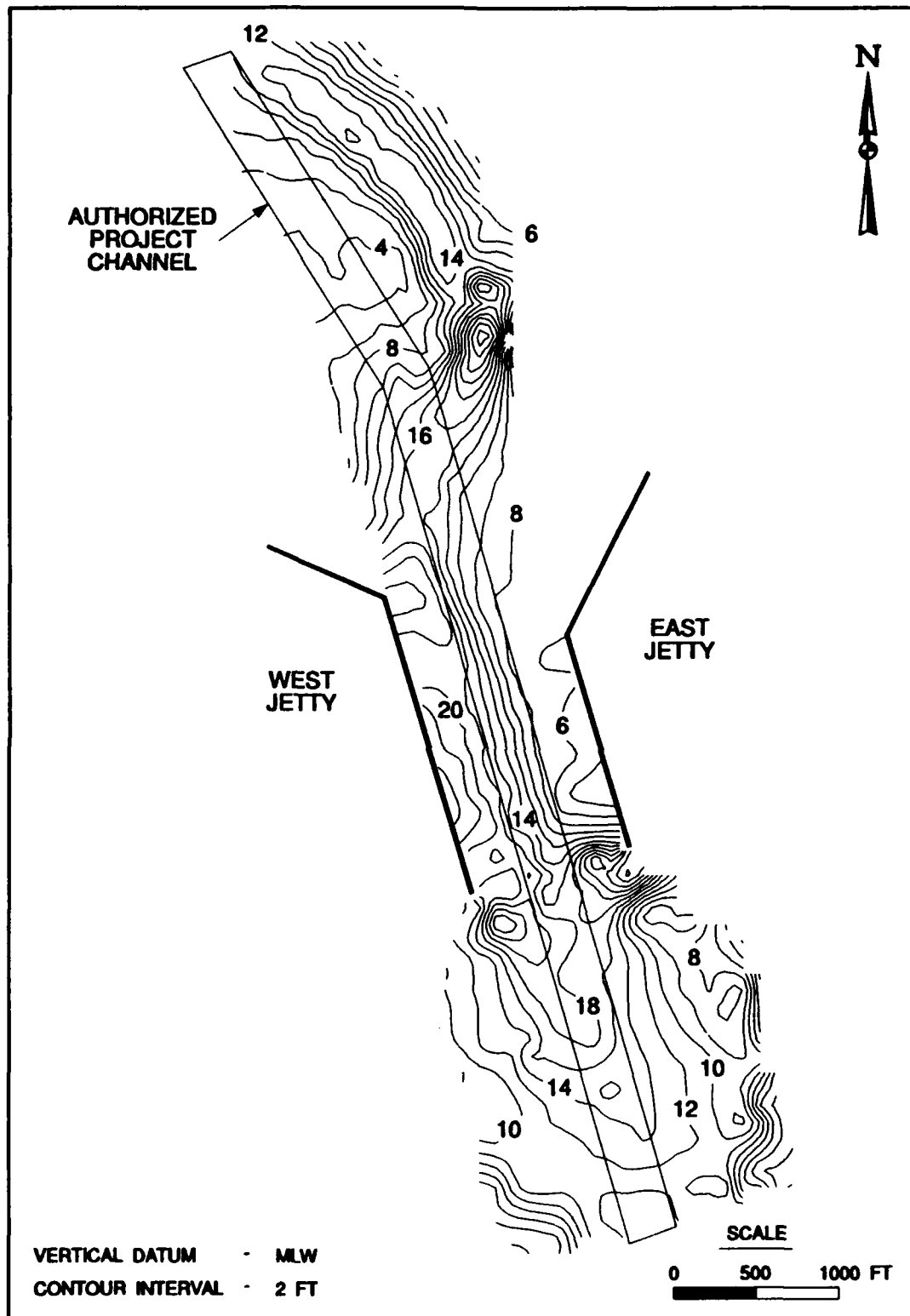


Figure 4. Channel migration and locations of scour at the Little River Inlet jetties

PART III: DATA COLLECTION AND ANALYSIS

23. Channel migration and scour at the jetty structures are important project concerns relative to potential dredging and nourishment operations within Little River Inlet. The following data collection and analysis program was initiated to perform a reconnaissance level review of channel stability and inlet hydrodynamics, with the objective of developing recommendations for an inlet maintenance and/or monitoring plan.

24. Three major study elements were included in this investigation to further develop sufficient knowledge of inlet processes: (1) analysis of the post-jetty inlet thalweg evolution; (2) measurement and analysis of prototype data, including tidal current measurements and side-scan sonar of the structures; (3) review of the Little River Inlet physical model study (Seabergh and Lane 1977).

Post-Jetty Inlet Thalweg Evolution

Contour plots

25. An analysis of pre- and post-jetty profile and bathymetry data was conducted to examine a chronological sequence of events, adding insight into the forcing functions which dynamically change the inlet. The time history also provides useful information when considering episodic events and possible relationships between storms and inlet changes.

26. Table 1 provides a list of survey data sets used in the channel thalweg evolution analysis. As part of the monitoring program, SAC conducted both beach profile surveys (which included lines within the inlet, parallel to the jetties, about 200 ft apart) and separate, more-detailed bathymetric surveys of the inlet. The beach profile data sets were entered into the Interactive Survey Reduction Program (ISRP) (Birkemeier 1984) for analysis purposes. The ISRP beach profile data then were imported into Radian Corporation's Contour Plotting System (CPS-3) software. The bathymetric survey data sets were digitized using a CALCOMP 9000 system and imported into CPS-3. Contour maps were generated for 13 surveys between April 1981 and June 1991 (Figures 5 to 17). Due to contrasts in detail of the data, the two types of data sets were gridded differently, and therefore should not be quantitatively compared. Contour difference plots were generated to indicate channel

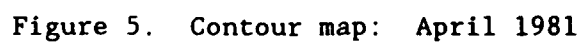
Table 1
Little River Inlet Channel Surveys

Survey Date	Survey Type
April 1981	Profile Line Survey
May 1982	Profile Line Survey
April 1983	Profile Line Survey
April 1984	Profile Line Survey
June 1985	Profile Line Survey
June 1986	Profile Line Survey
July 1988	Bathymetric Survey
December 1989 (Post-Hugo)	Profile Line Survey
June 1990	Bathymetric Survey
August 1990	Bathymetric Survey
November 1990	Bathymetric Survey
March 1991	Bathymetric Survey
June 1991	Bathymetric Survey

evolution from April 1984 (post-fill survey) to June 1986 (Figure 18) and for the bathymetric data sets from June 1990 to June 1991 (Figure 19).

Cross-sectional areas

27. Cross-sectional areas were computed for each survey data set along the cross-sectional profile designated in Figure 20. Although the calculated areas represent changes across only one section of the inlet channel, they allow a rough estimate of changes in stability across that portion of the channel. Channel cross-sections for each date were depicted using CPS-3, and then areas (to MLW) were digitized and computed using the CALCOMP 9000 system (Table 2). The area at this location has gradually increased over the period between 1983 and 1991; however, these are not considered major increases relative to accuracy of methods used to calculate the values. This analysis indicates that the inlet cross-section is still changing and has not yet reached a long-term equilibrium condition.



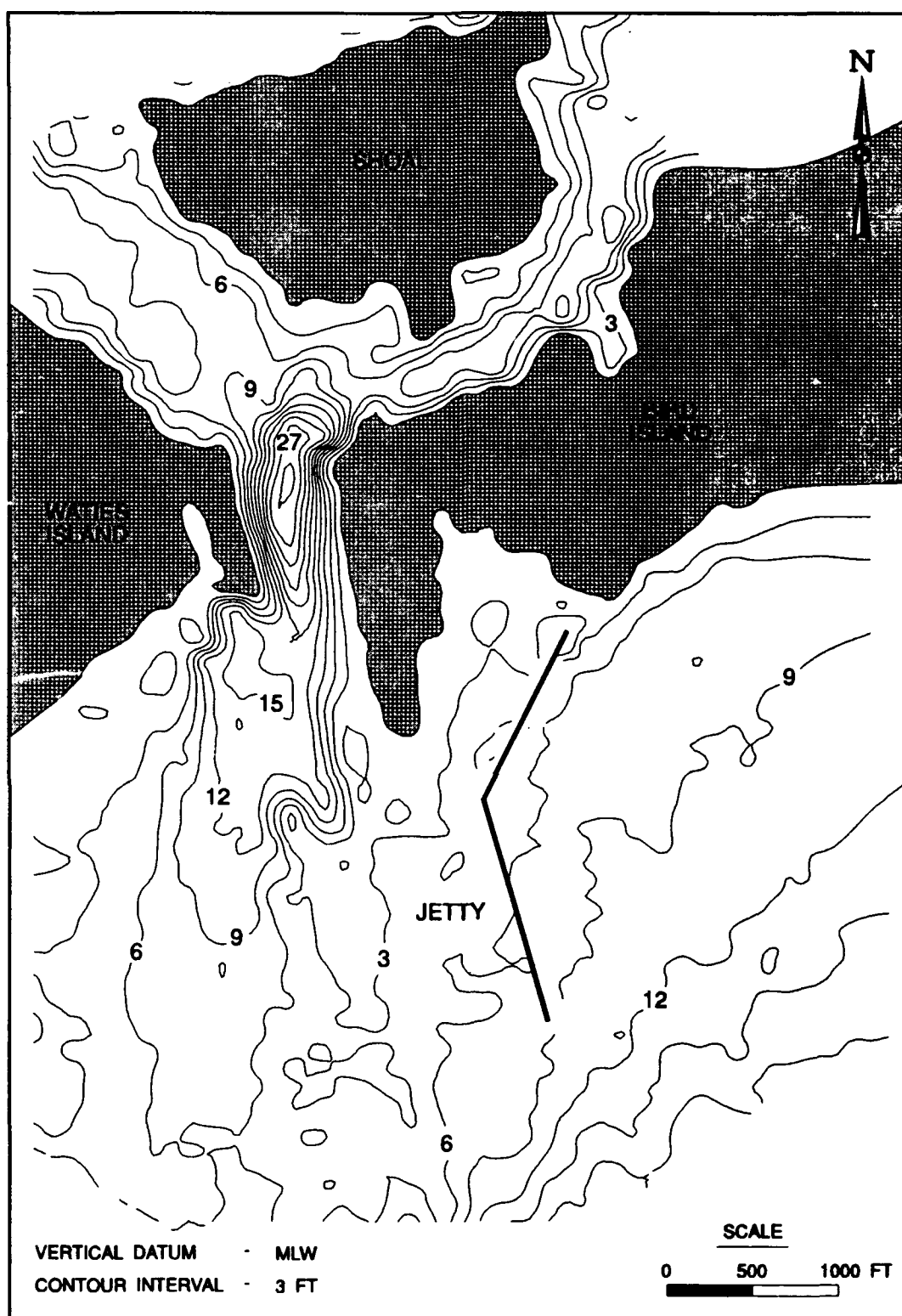


Figure 6. Contour map: May 1982

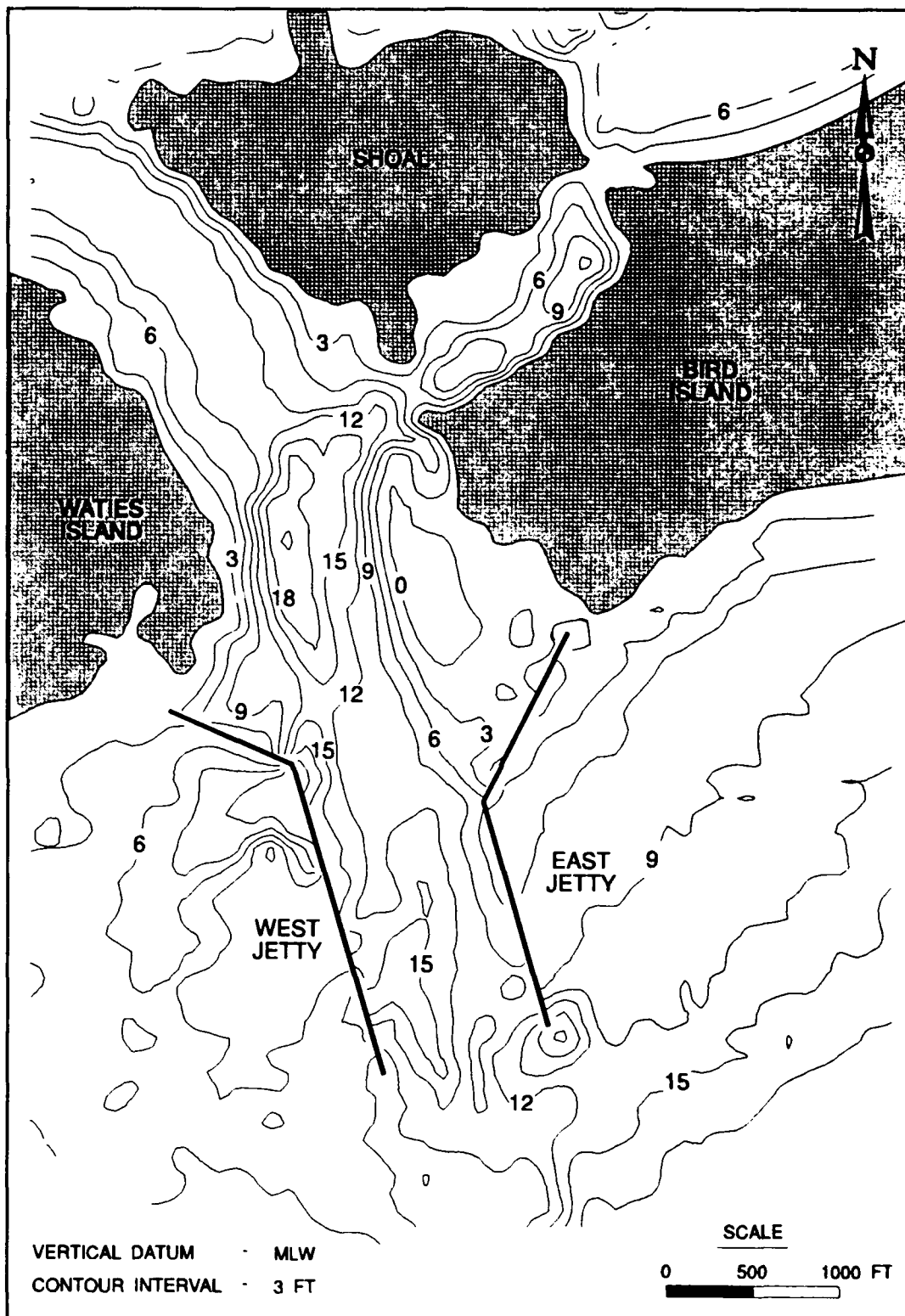


Figure 7. Contour map: April 1983

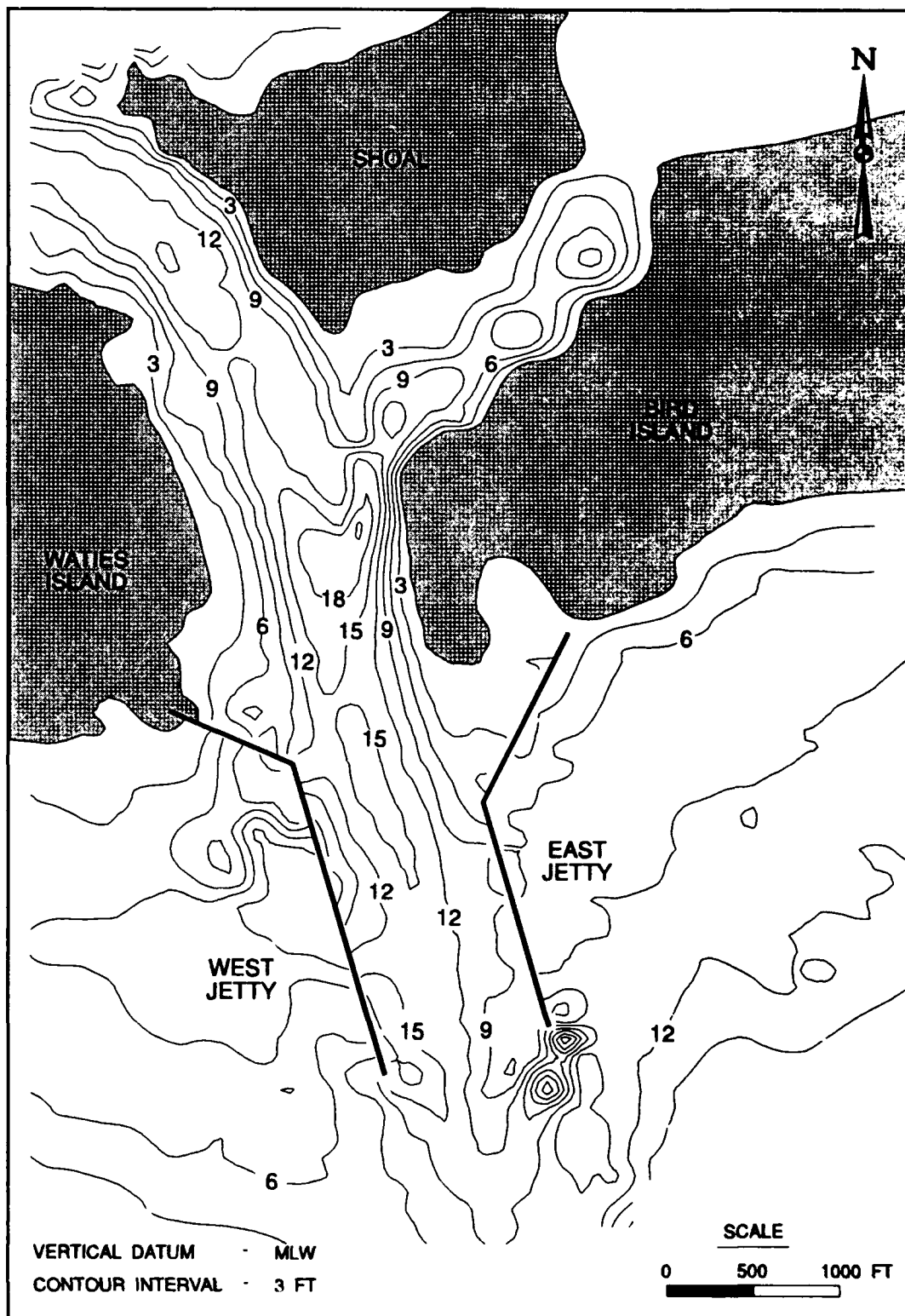


Figure 8. Contour map: April 1984

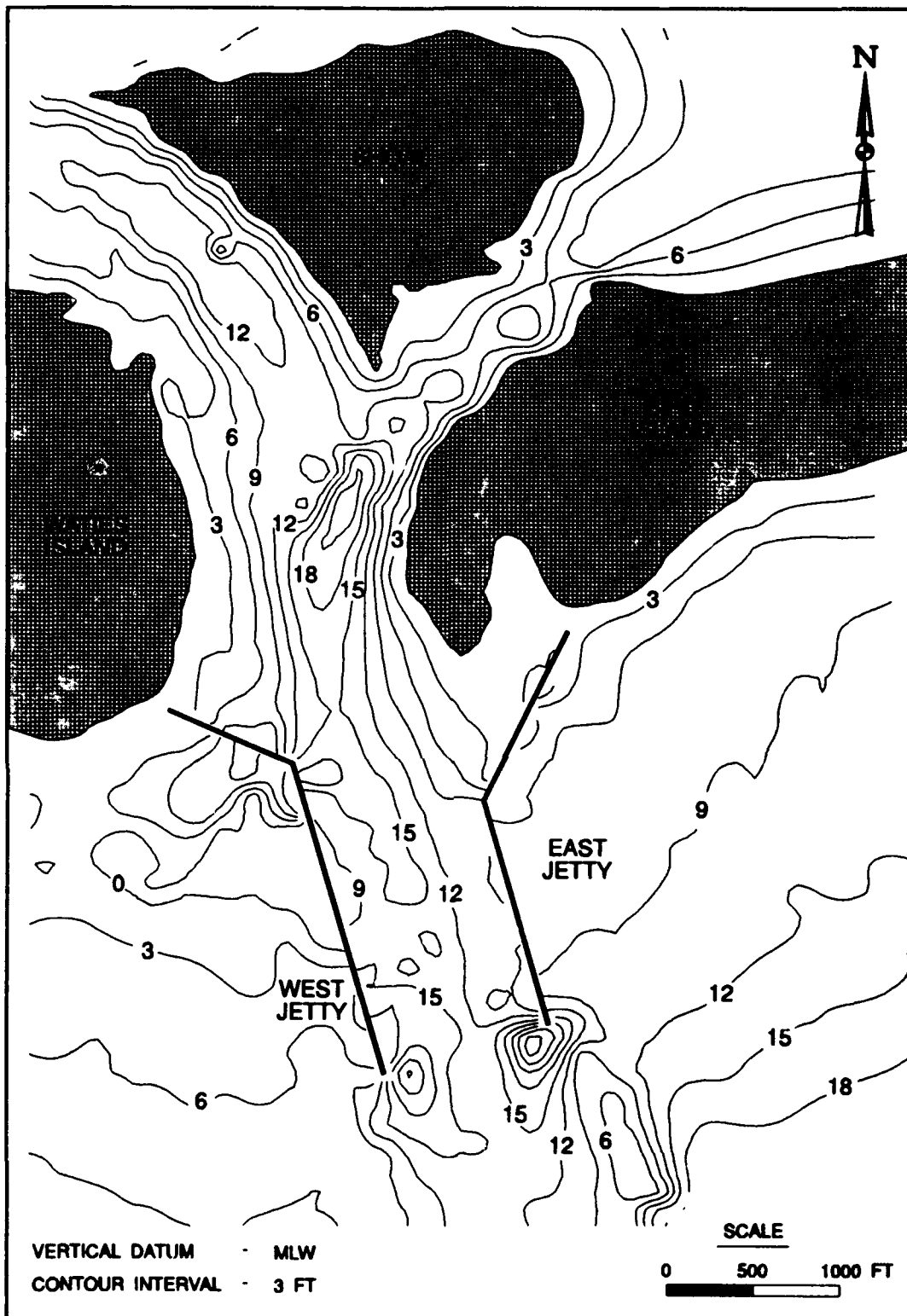


Figure 9. Contour map: June 1985

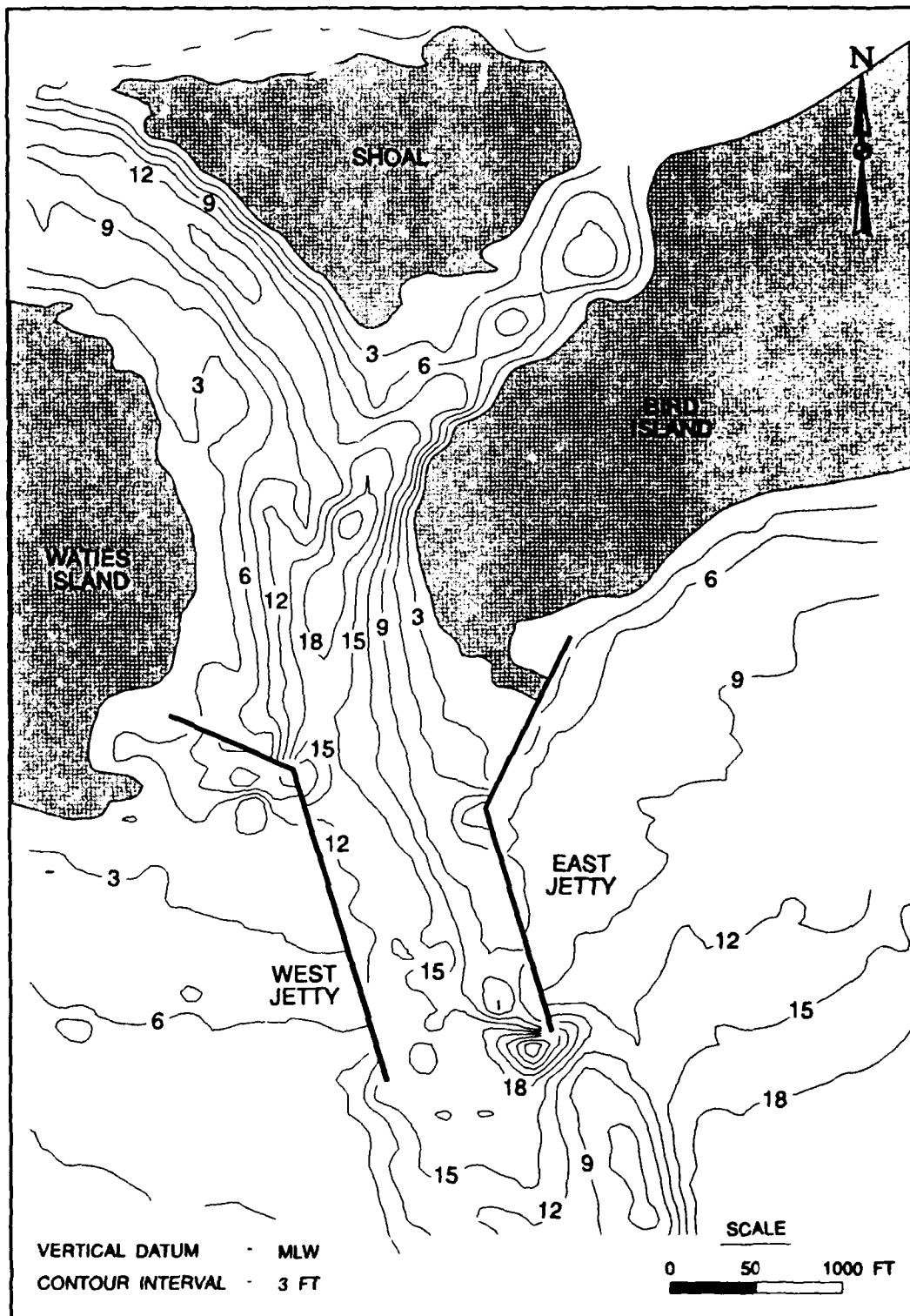


Figure 10. Contour map: June 1986

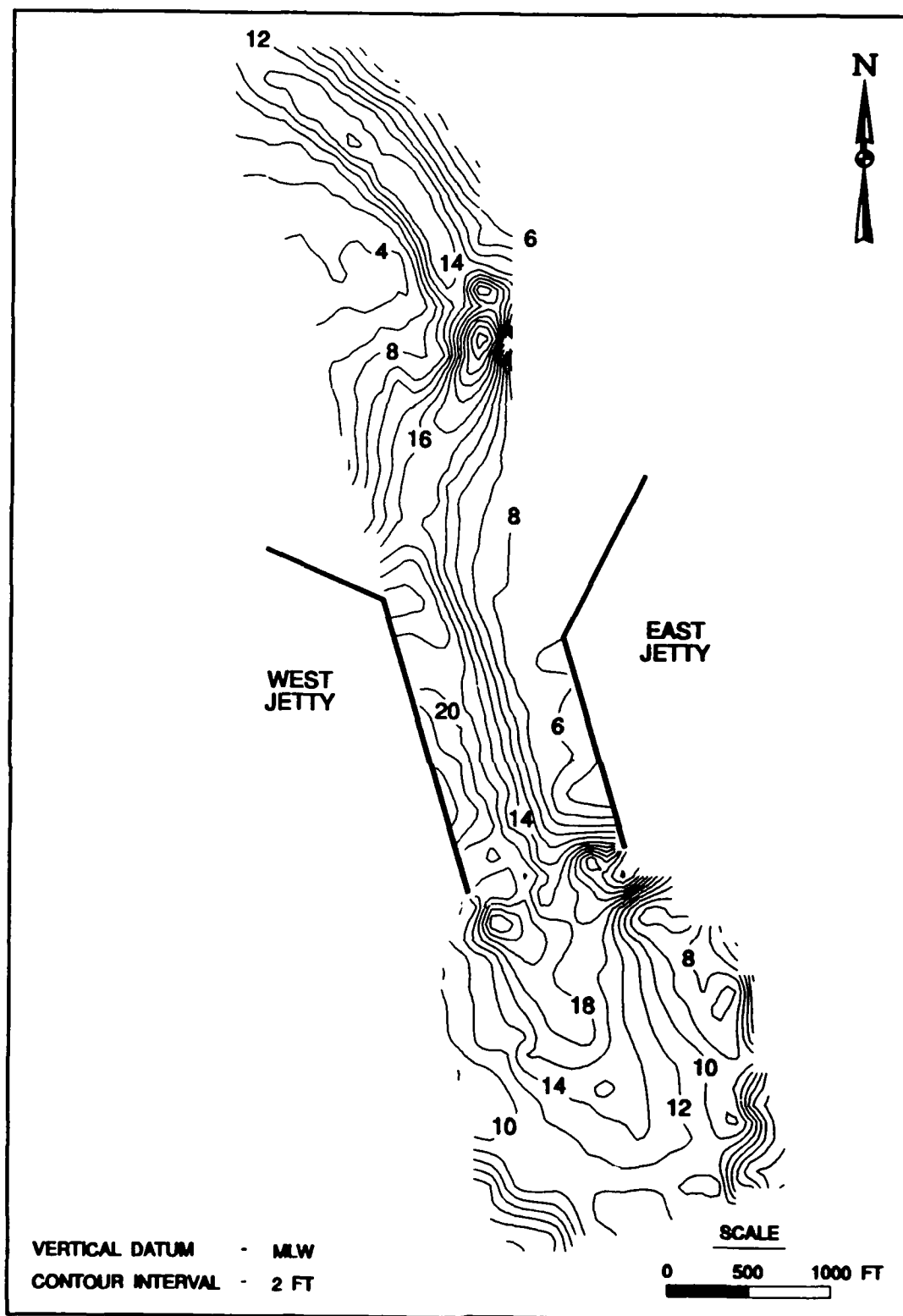


Figure 11. Contour map: July 1988

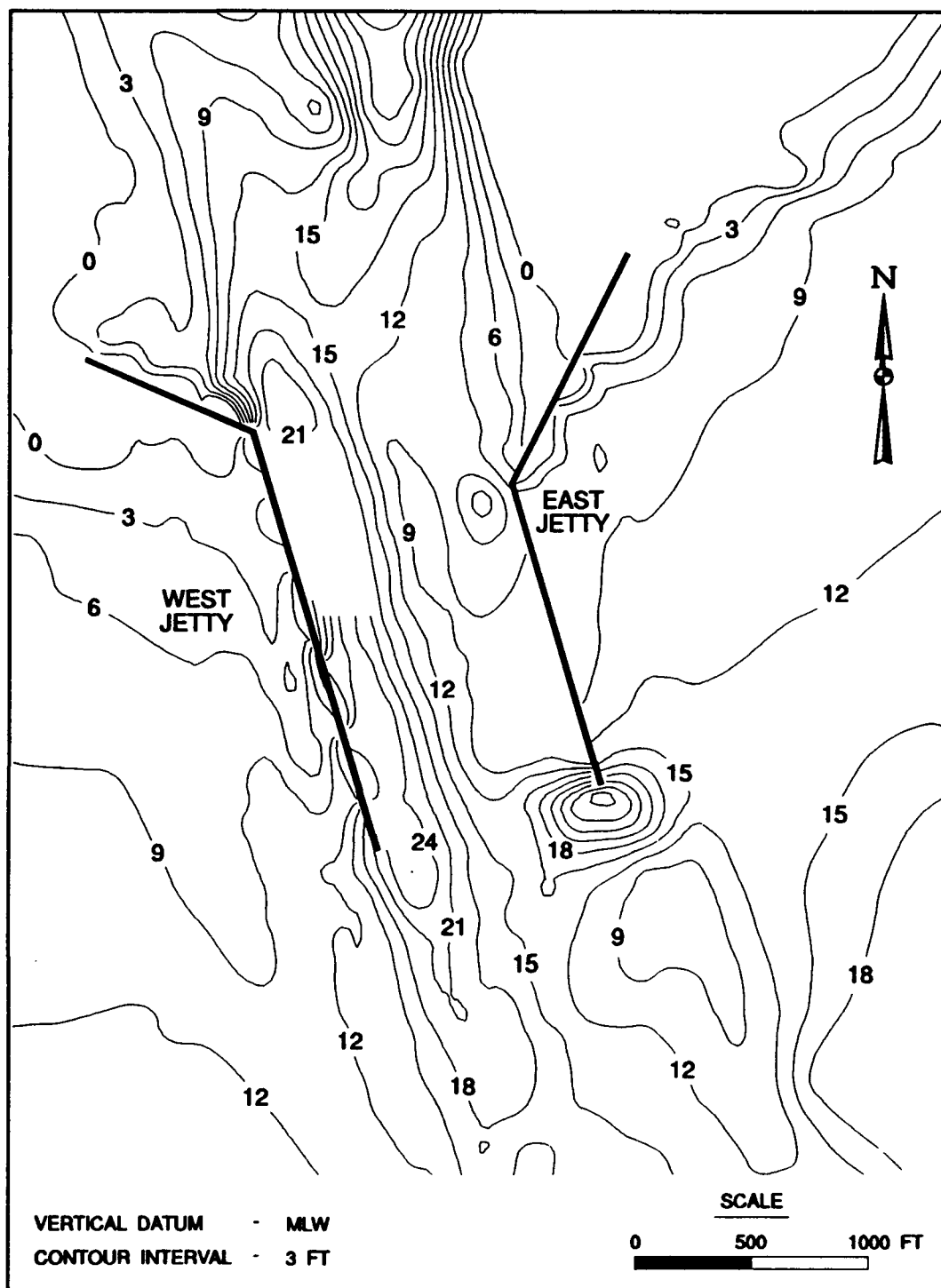


Figure 12. Contour map: December 1989 (post-Hurricane Hugo)

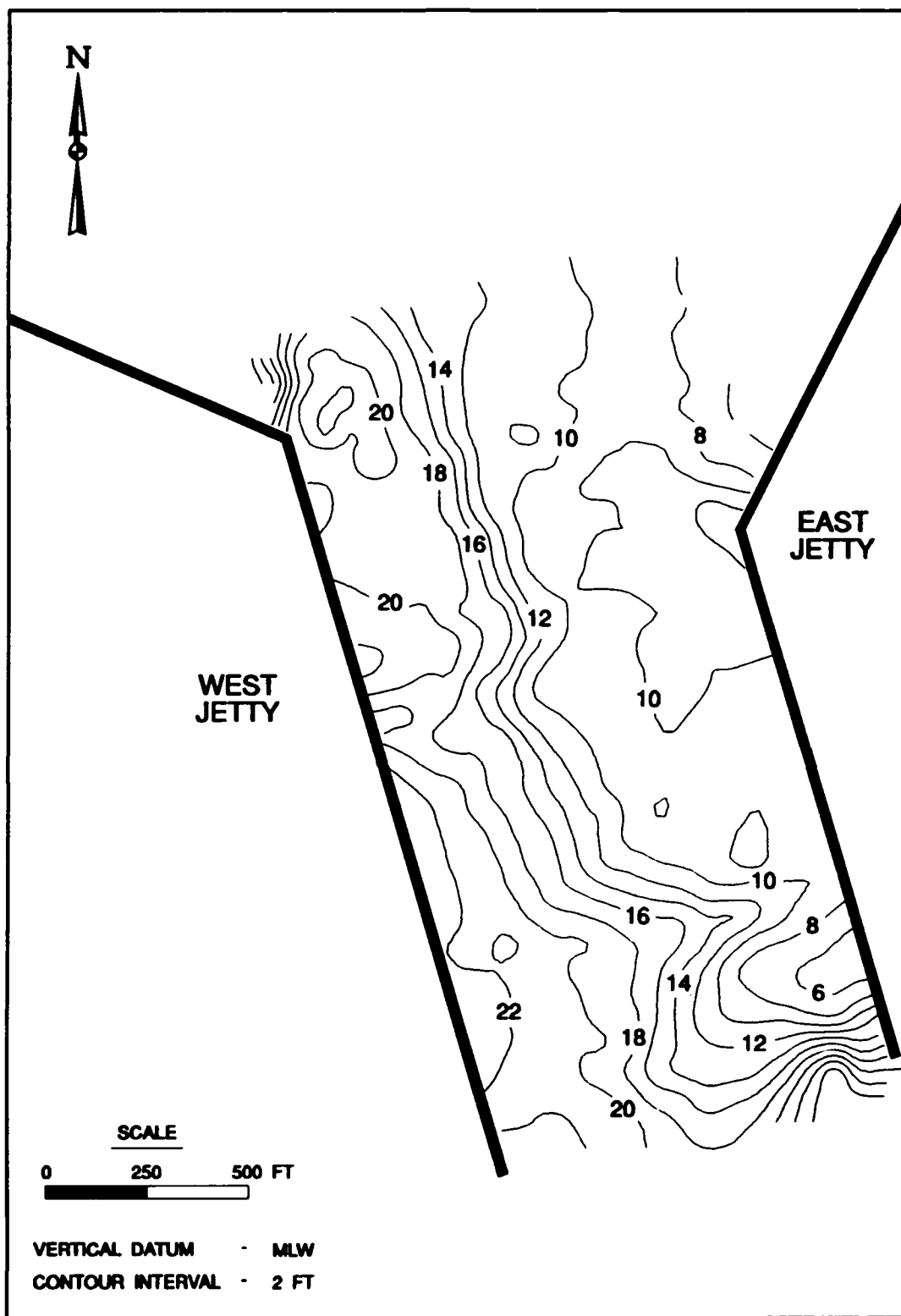


Figure 13. Contour map: June 1990

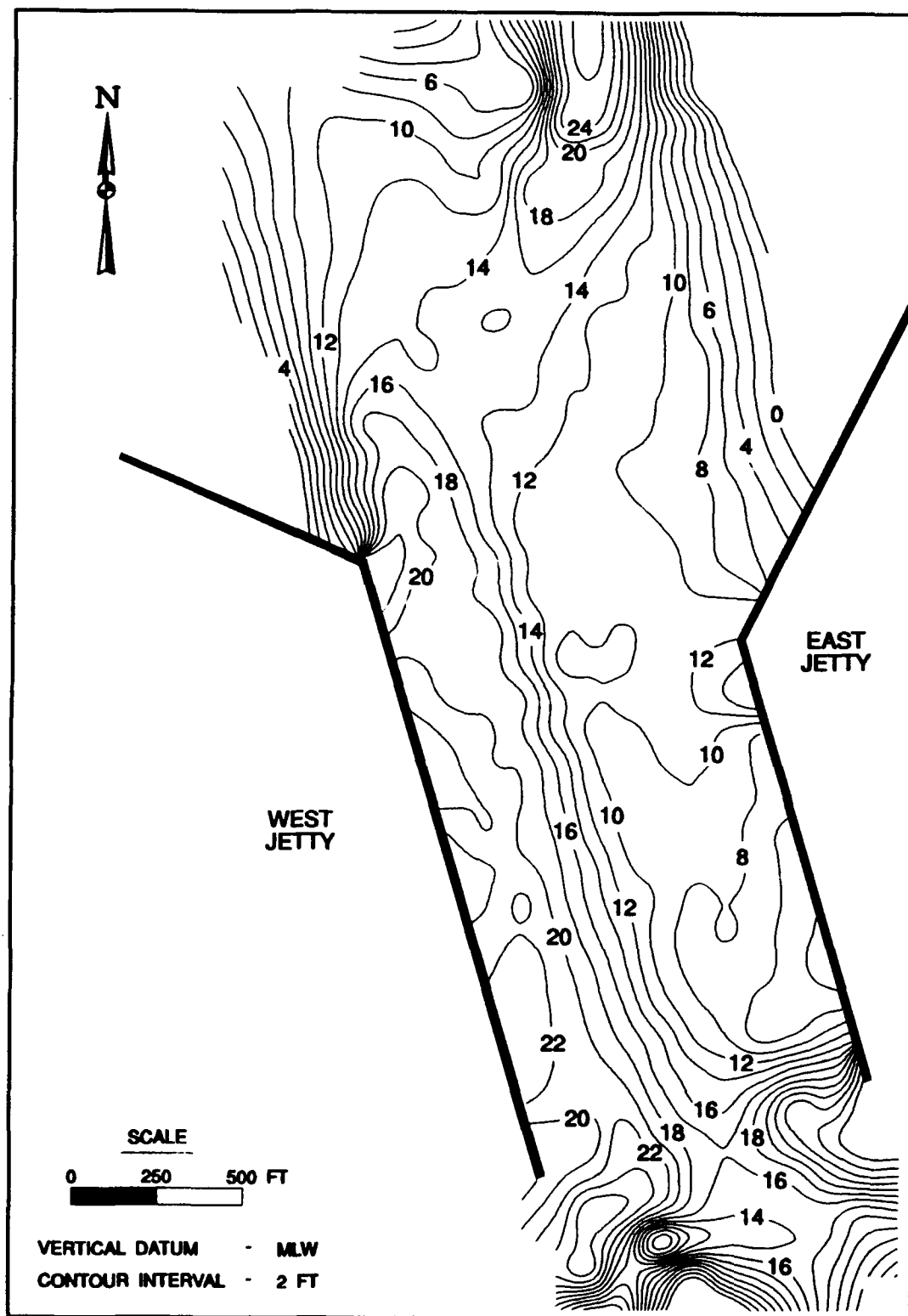


Figure 14. Contour map: August 1990

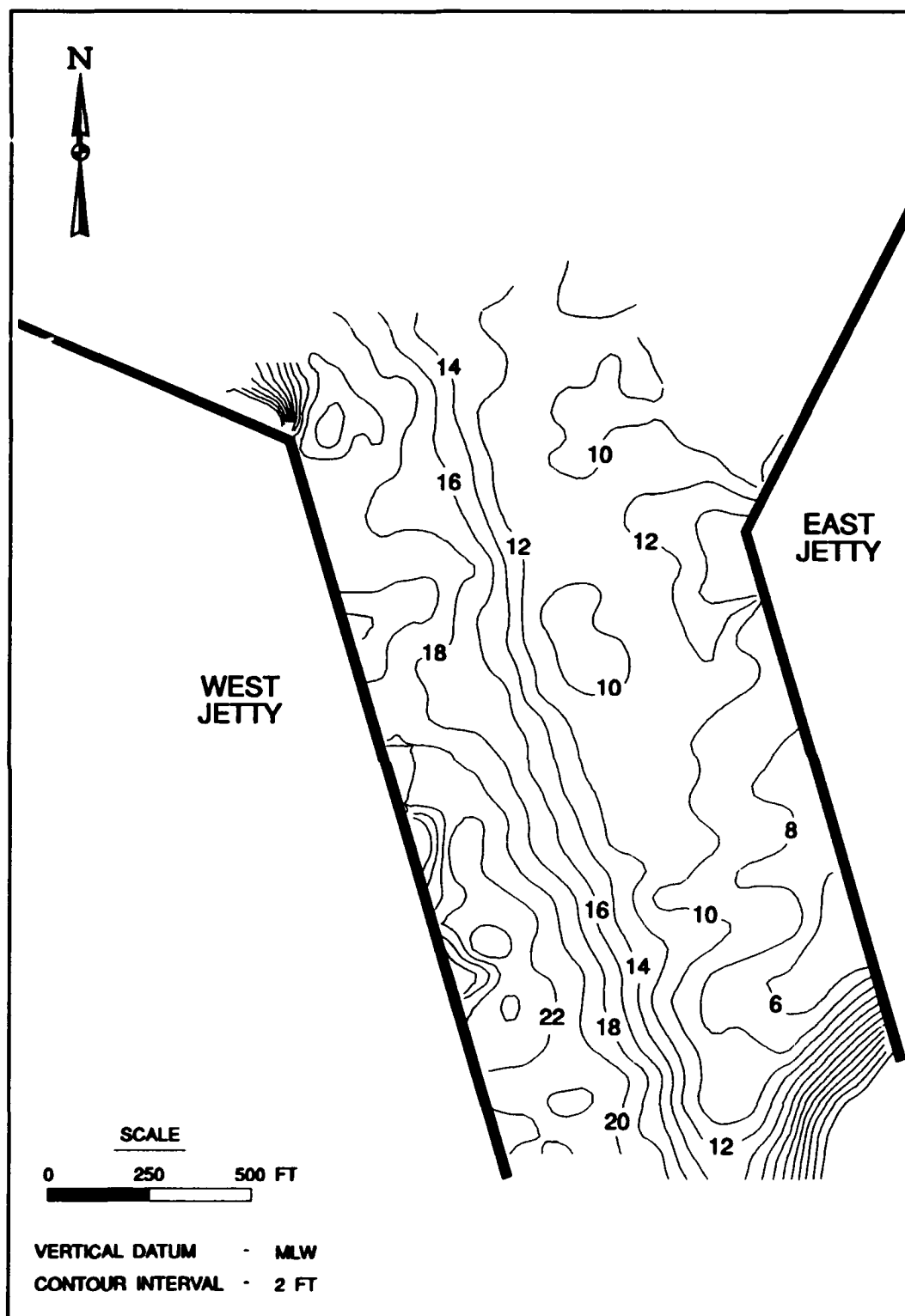


Figure 15. Contour map: November 1990

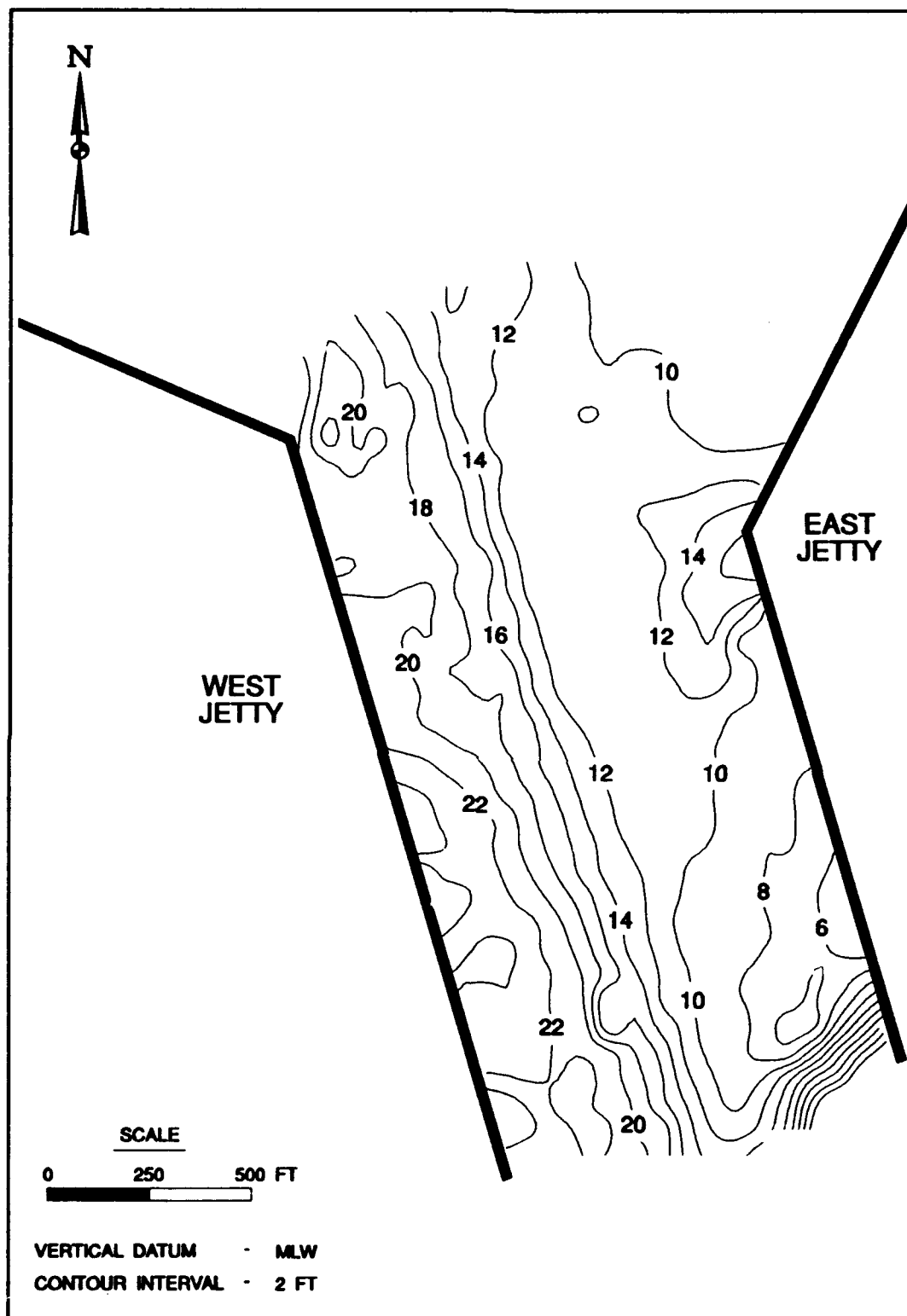


Figure 16. Contour map: March 1991

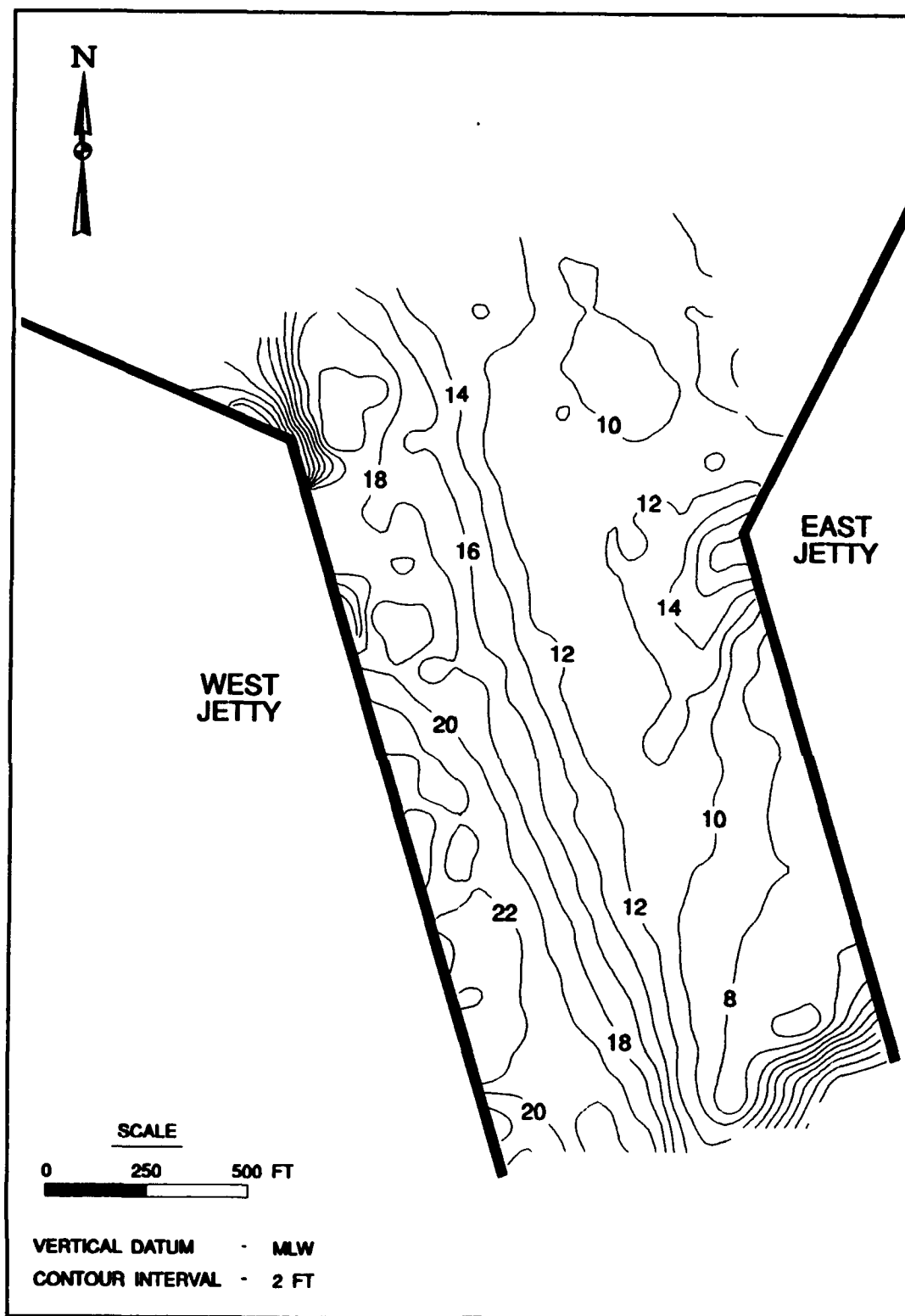


Figure 17. Contour map: June 1991

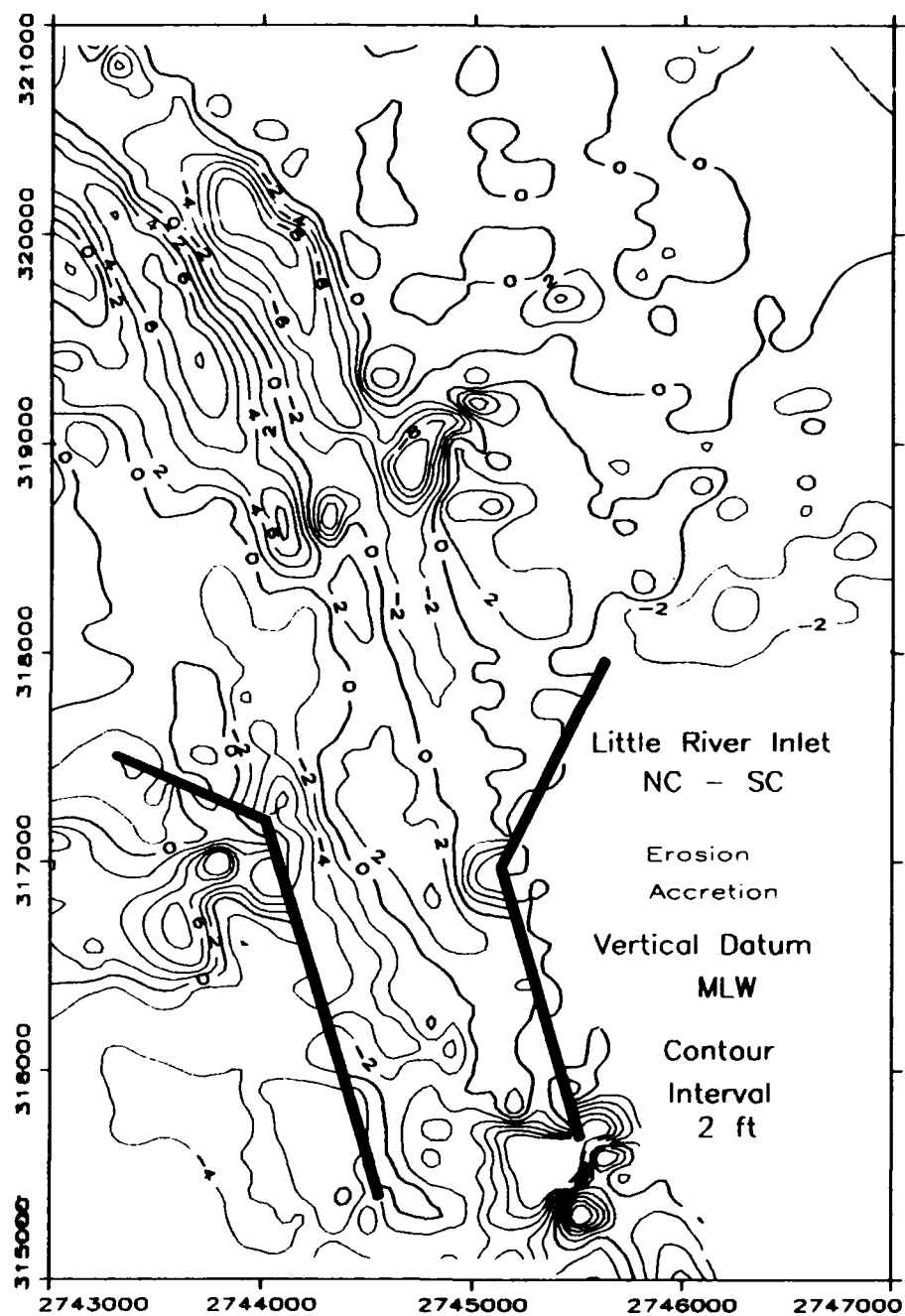


Figure 18. Contour difference map: April 1984 (post-fill) to June 1986

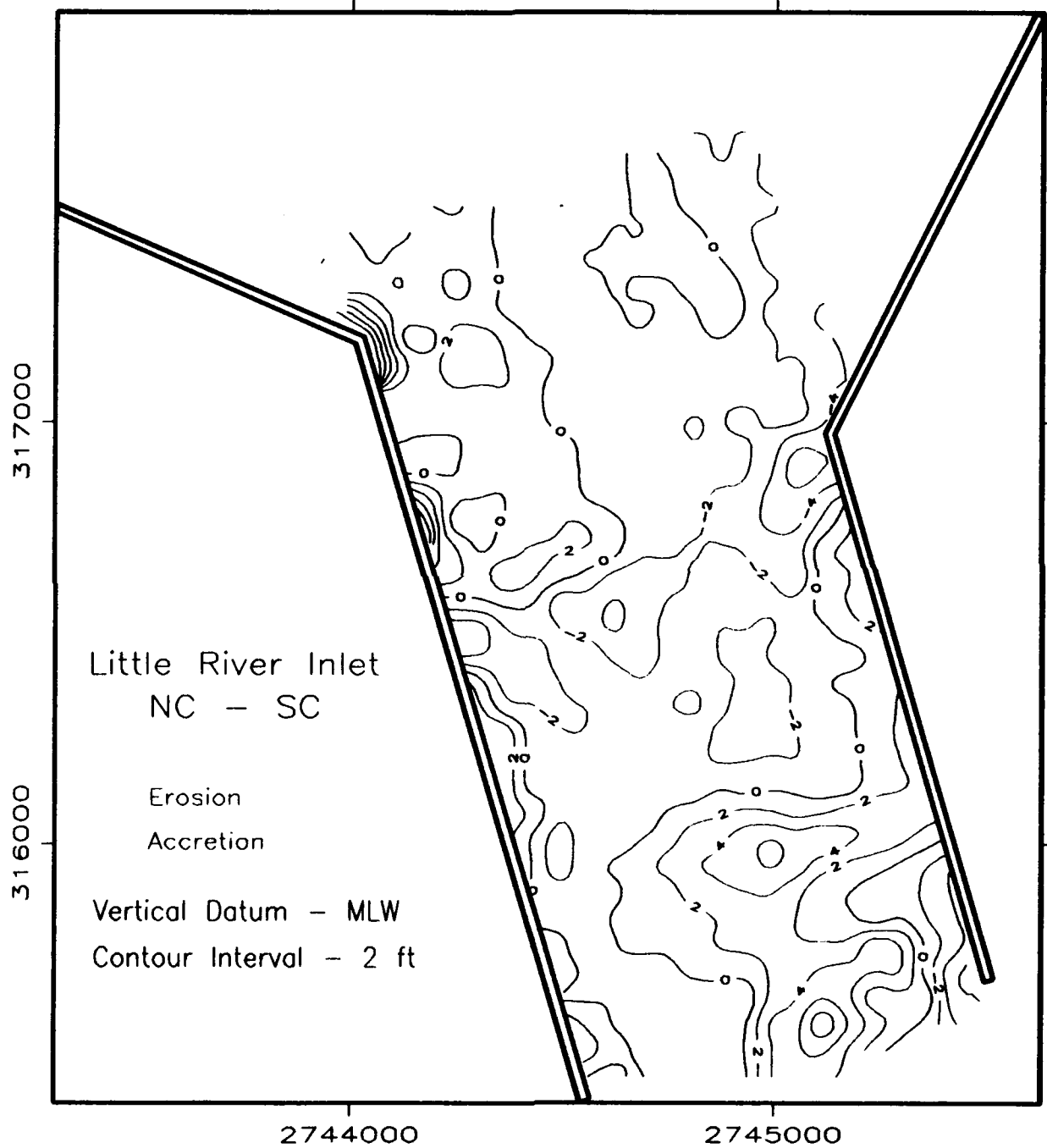


Figure 19. Contour difference map: June 1990 to June 1991

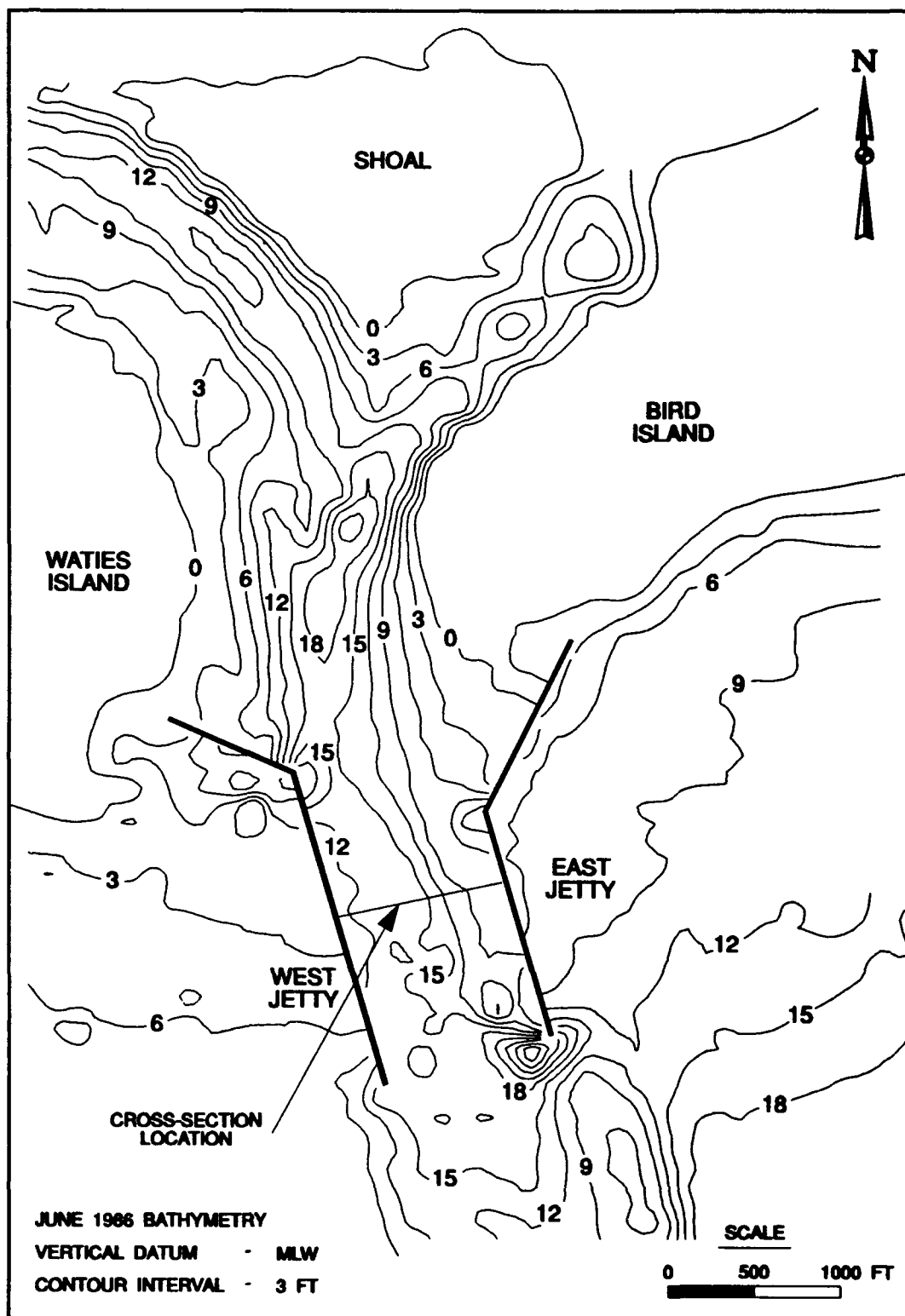


Figure 20. Location of profile used to calculate cross-sectional areas

Table 2
Little River Inlet Cross-sectional Areas

Survey Date	Area (MLW, ft ²)	Comments
April 1983	11,030	During west jetty construction
April 1984	10,810	Post-dredging and fill
June 1985	12,050	None
June 1986	12,410	None
July 1988	12,690	None
December 1989	13,050	Post-Hugo survey
June 1990	12,570	None
November 1990	13,069	None
March 1991	14,120	None
June 1991	13,640	None

Measurement and Analysis of Prototype Data

Current data

28. A field data collection effort was conducted to assess existing hydrodynamic conditions, define the flow field through the inlet, and identify flow patterns and velocities through scour areas along the west jetty. Dominant flow patterns through the inlet and the two channels which lead into the inlet are key factors relative to stability of the main inlet channel.

29. The field investigation was conducted 21-23 May 1991, and consisted of current magnitude and direction measurements and a side-scan sonar survey of the west jetty. The field team consisted of four CERC personnel and three SAC representatives.

30. A 23-ft Sea Ox vessel equipped with a winch was used for the field study. An InterOcean Systems Model S-4 current meter was used to collect the two-dimensional current data, which operates by creating a magnetic field and sensing voltage fluctuations induced by the movement of water through the field (InterOcean Systems, Inc. 1987). The current meter was linked directly to a lap-top computer on board the vessel for data logging.

31. On 22 May 1991, vertical profiles of current speed and direction were measured at nine stations between the jetties and across the two channels leading into the inlet (Figure 21). Measurements were taken at two to three different depths (bottom, middle, and surface), and were obtained at approximately 1-1/2-hr intervals over a 13-hr time period. Stations 4 and 5 were monitored to determine flow patterns and scour currents through these deeper areas, especially at peak flood and ebb tides. Navigation conditions prevented collecting current data at the east jetty tip scour hole.

32. Water level measurements were made during current data collection using two staff gages placed within the inlet throat. Plots of measured and predicted (National Oceanic and Atmospheric Administration, National Ocean Service 1991) tides are shown on Figure 22. Locations of the two tidal staff gages are shown on Figure 21.

33. Current data were analyzed using applications software (Version 2.67) provided with the S-4 current meter. Figures 23 through 31 show data plotted in vector format for each cycle around the nine stations. Each vector depicts average magnitude and direction for bottom, middle, and surface currents measured at each station. Figures 32 through 40 show average current speed plotted through time for Stations 1 through 9, respectively.

Tidal prism calculations

34. A rough estimate of the post-jetty tidal prism was computed by using current data collected on 22 May 1991 and bathymetry data collected in June 1991. Tidal current velocities were averaged for Stations 1, 2, and 3 (Figure 21) for each cycle around the stations. A cross-sectional area A_c then was computed for each velocity V_{avg} , adjusting the areas appropriately for changes in tidal elevations. Average discharge Q through the inlet was calculated for each using the continuity equation:

$$Q = V_{avg}A_c$$

A plot then was constructed of discharge versus time over the tidal cycle, and areas under the flood and ebb portions of the curve were computed. These areas represent the respective ebb and flood tidal prisms over that specific tidal cycle, and were calculated as 680 million cu ft for the ebb tidal prism

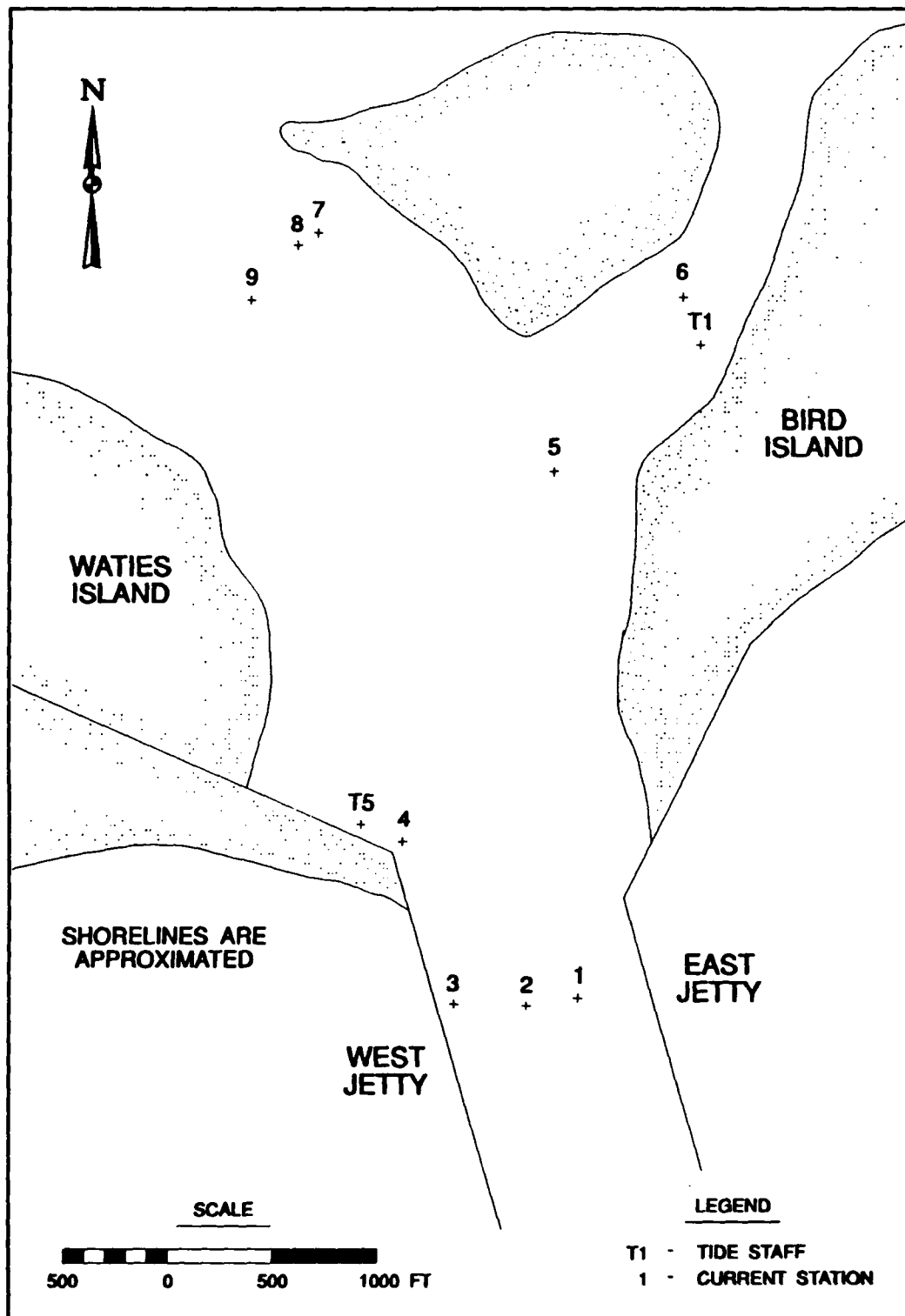


Figure 21. Stations used for tidal current monitoring

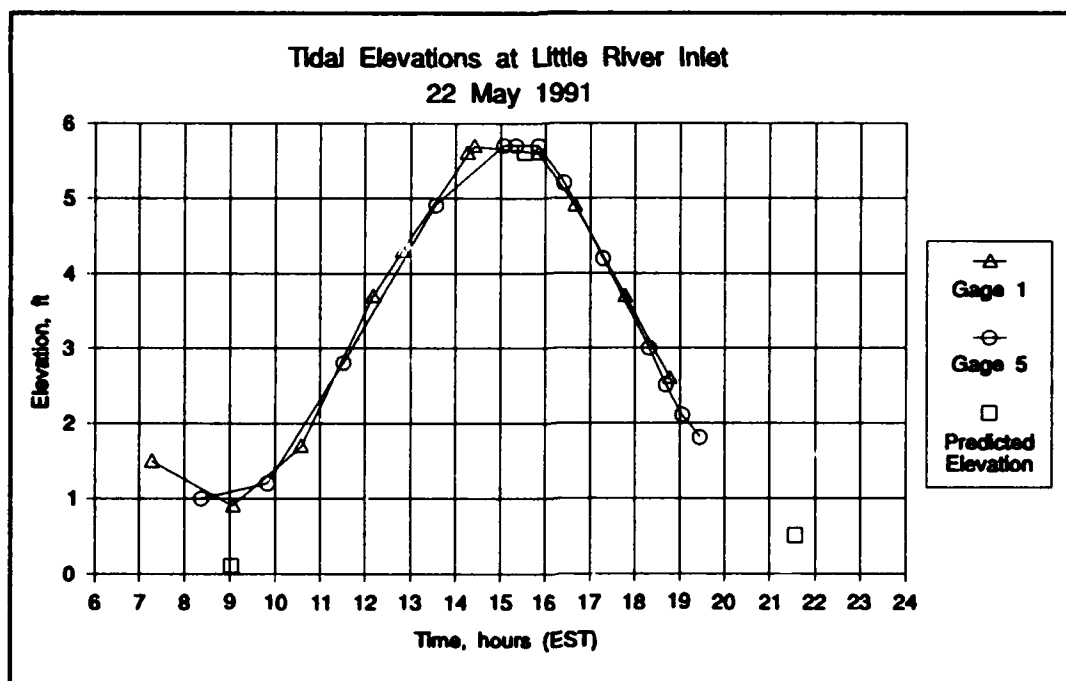


Figure 22. Measured and predicted tides, 22 May 1991

and 585 million cu ft for the flood tidal prism. These values indicate an increase in prism from the average 505 million cu ft calculated by Seabergh and Lane (1977) for pre-jetty conditions.

35. United States Geological Survey freshwater inflow data were obtained for a gage site on the Waccamaw River near Longs, SC. Using instantaneous discharge data from 22 May 1991, a freshwater discharge of approximately 21 million cu ft over a tidal cycle was computed. This value is significantly less than the freshwater inflow value estimated in the tidal prism analysis (95 million cu ft). A number of reasons may influence this difference, including the fact that gage data at Longs, SC only accounts for one inflow location, and does not consider inflow to the Little River Inlet system from other sources such as the streams connecting with Mad Inlet. The possibility exists of a coupling with Mad Inlet, wherein the area floods through both inlets, but ebbs predominantly through Little River Inlet. Additionally, higher tidal elevations were predicted at Little River Inlet prior to 22 May 1991, indicating the possibility of some storage in the inlet system.

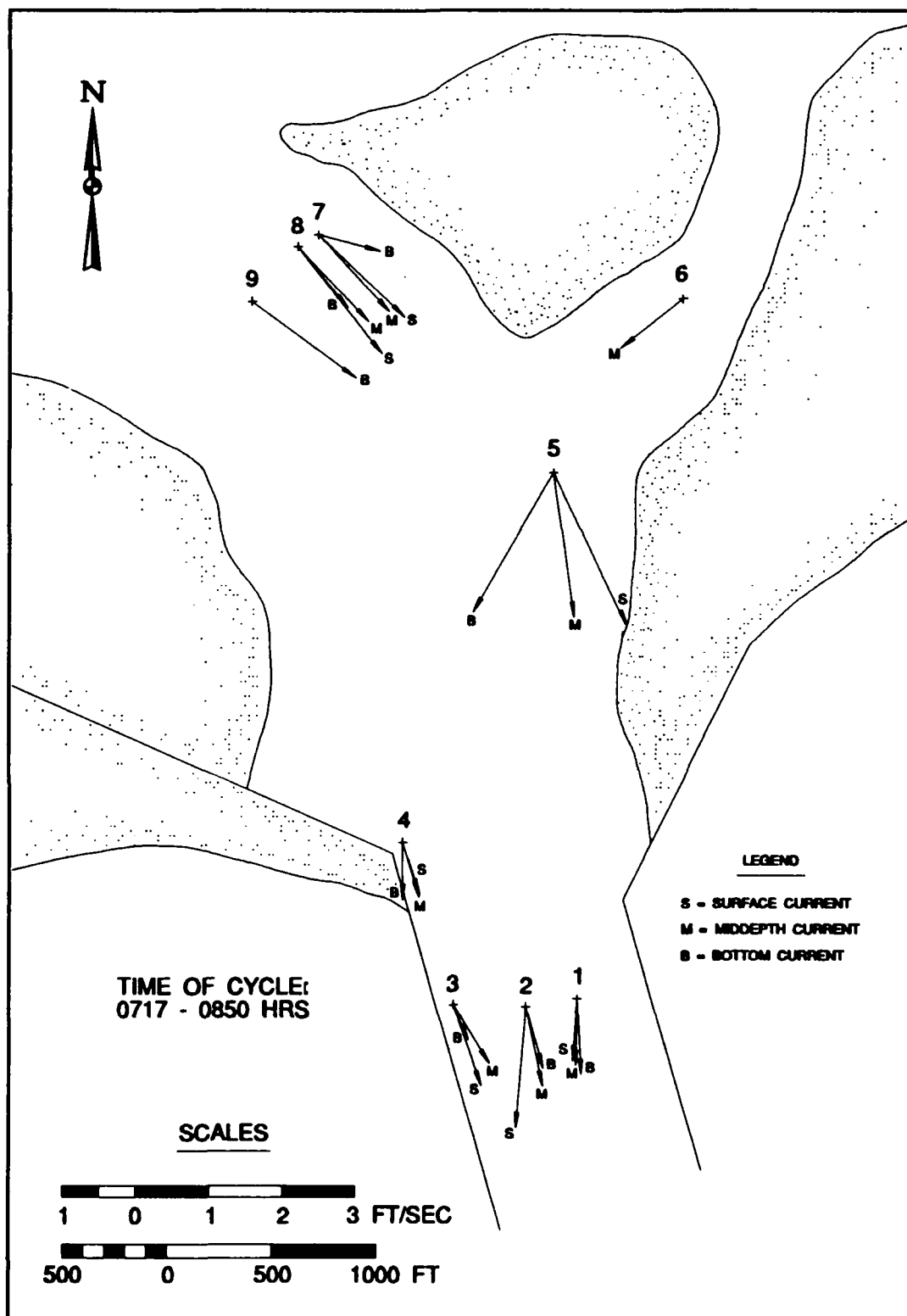


Figure 23. Tidal current data collected from 0717 to 0850 hr

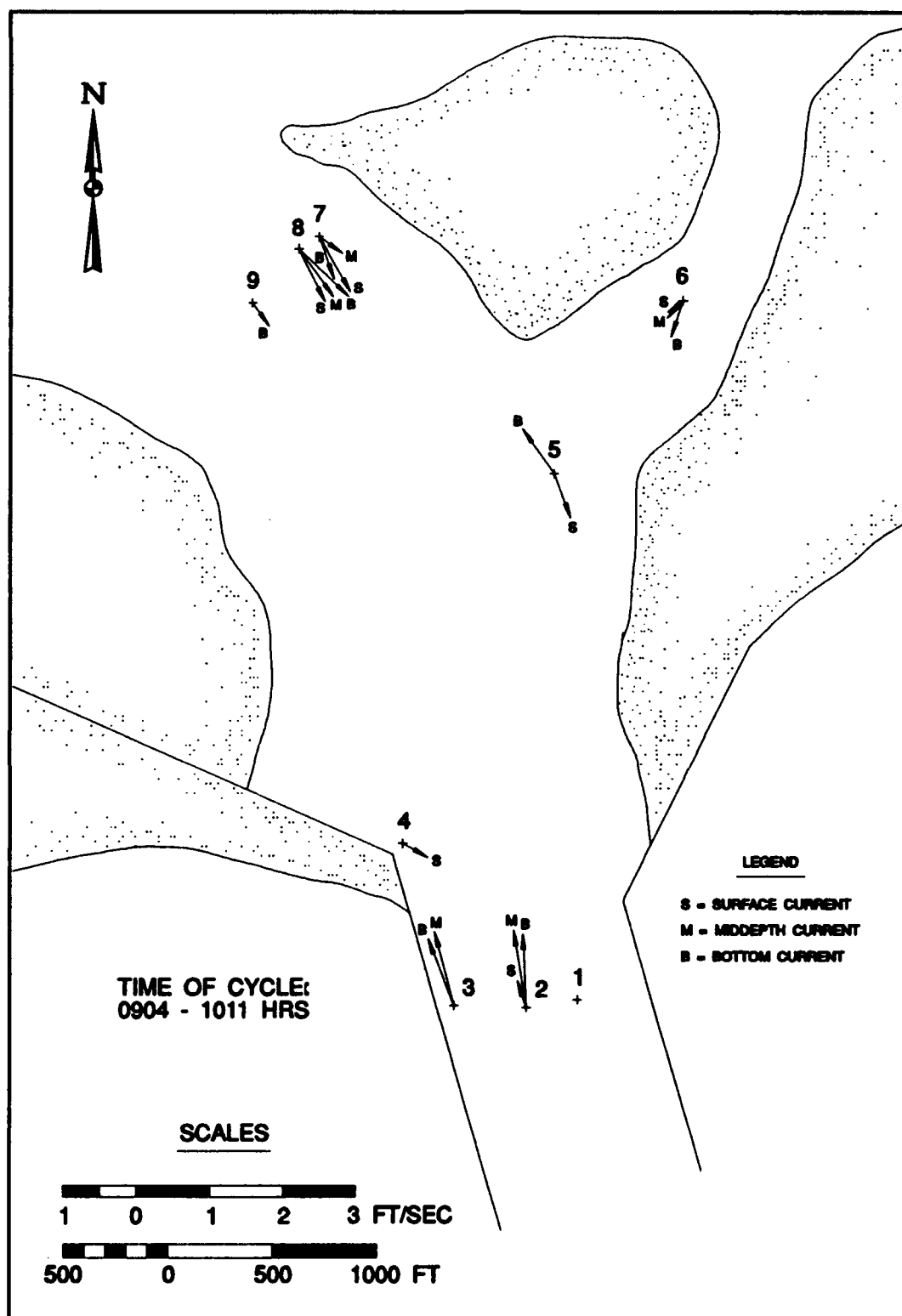


Figure 24. Tidal current data collected from 0904 to 1011 hr

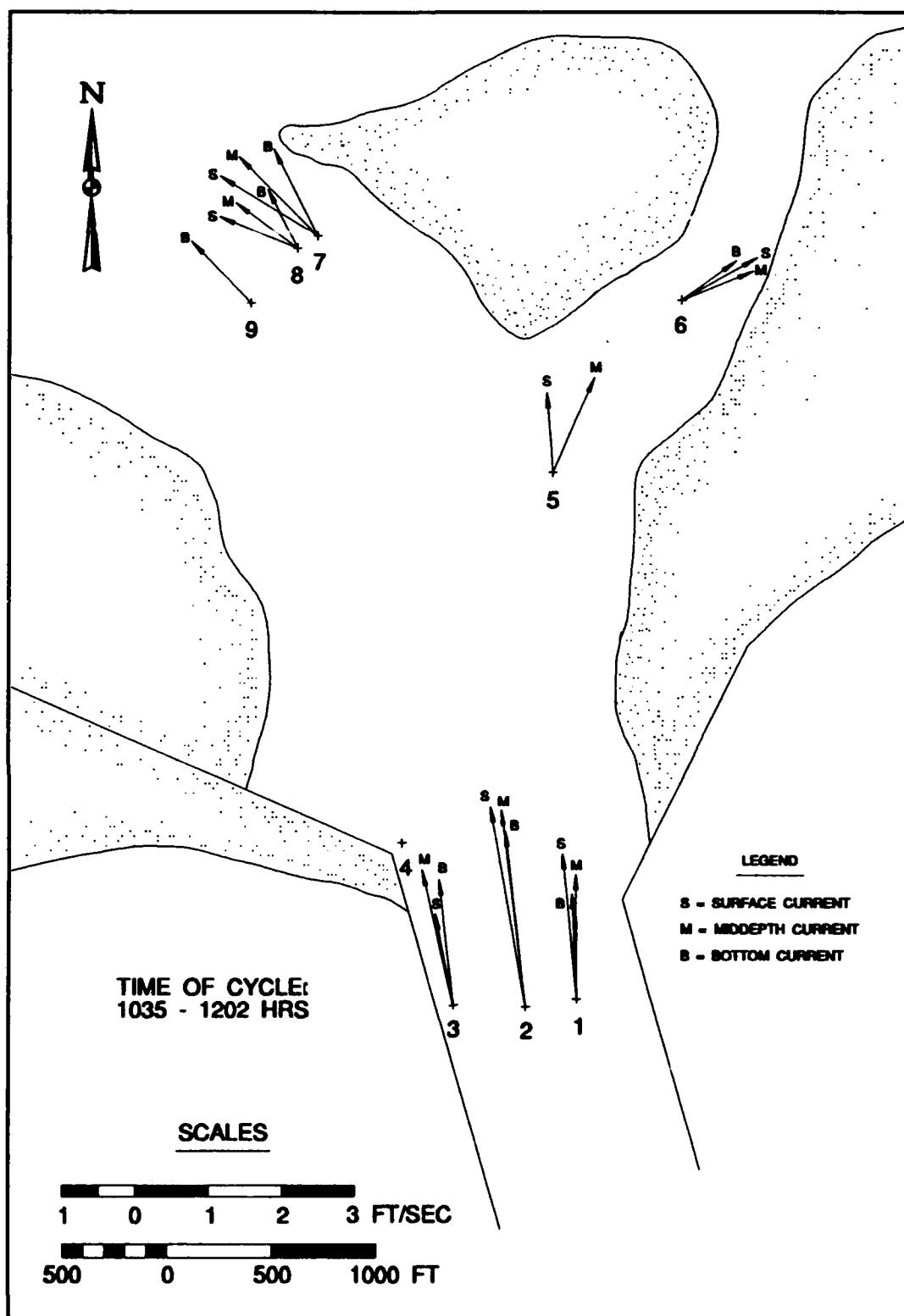


Figure 25. Tidal current data collected from 1035 to 1202 hr

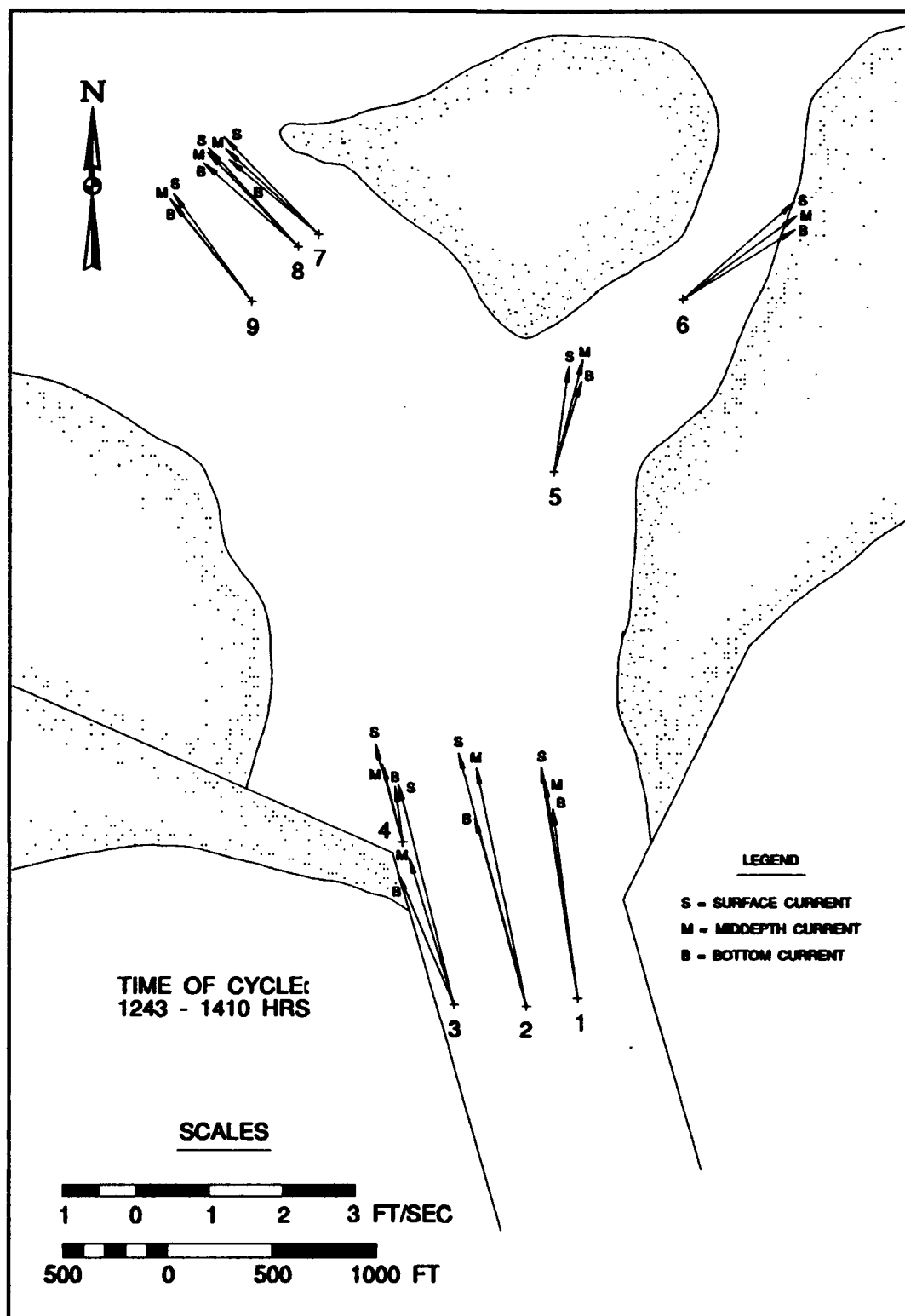


Figure 26. Tidal current data collected from 1243 to 1410 hr

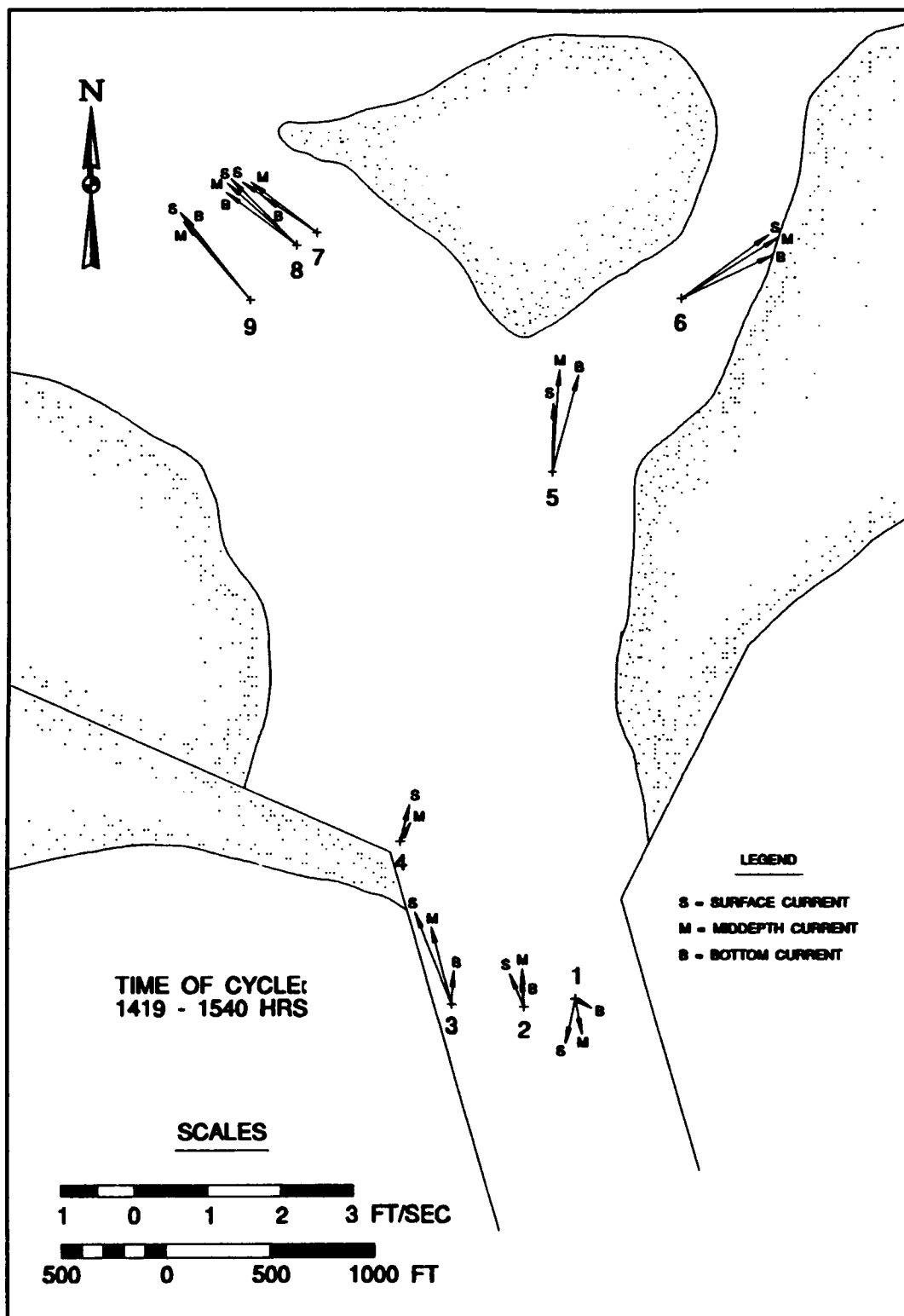


Figure 27. Tidal current data collected from 1419 to 1540 hr

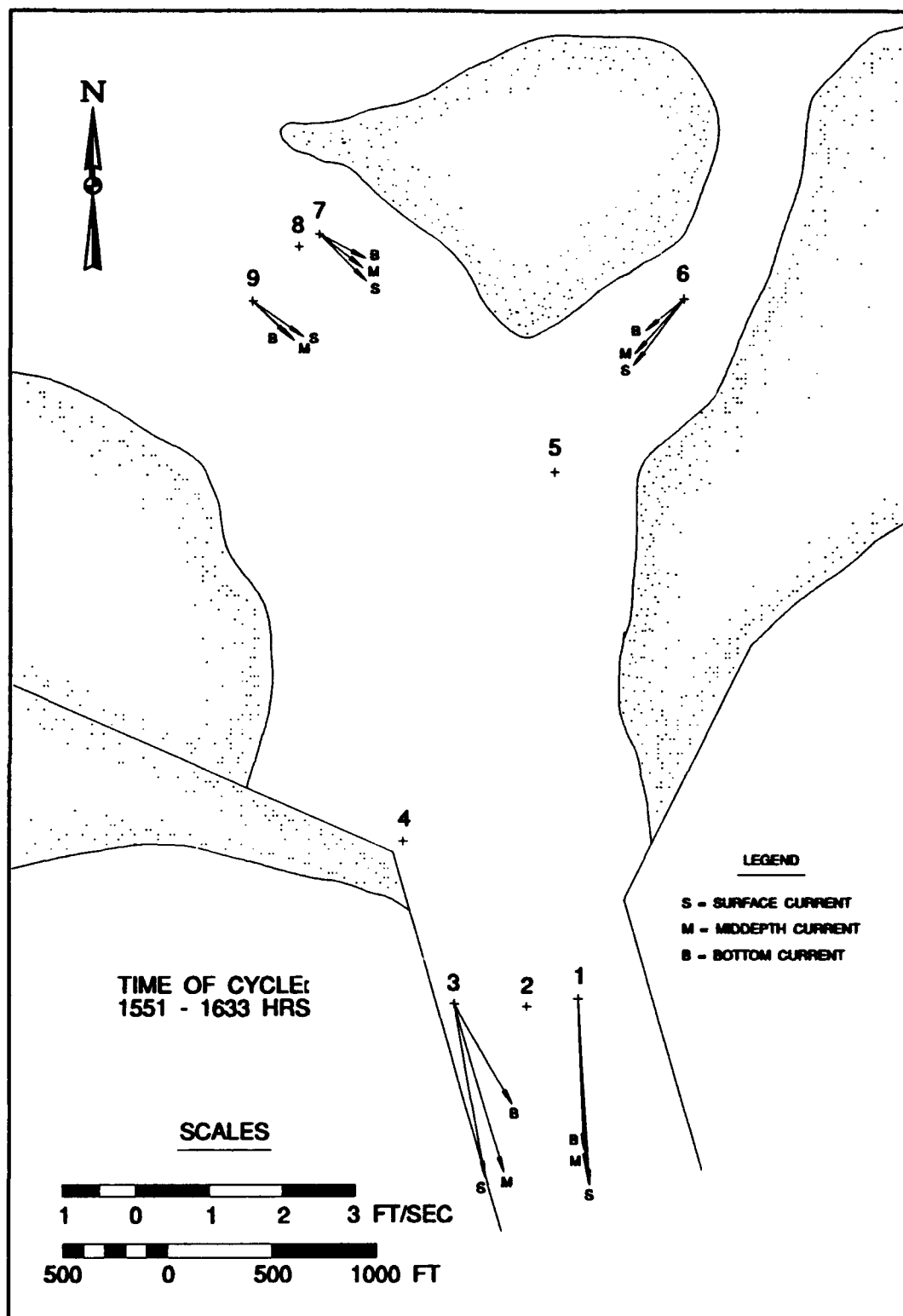


Figure 28. Tidal current data collected from 1551 to 1633 hr

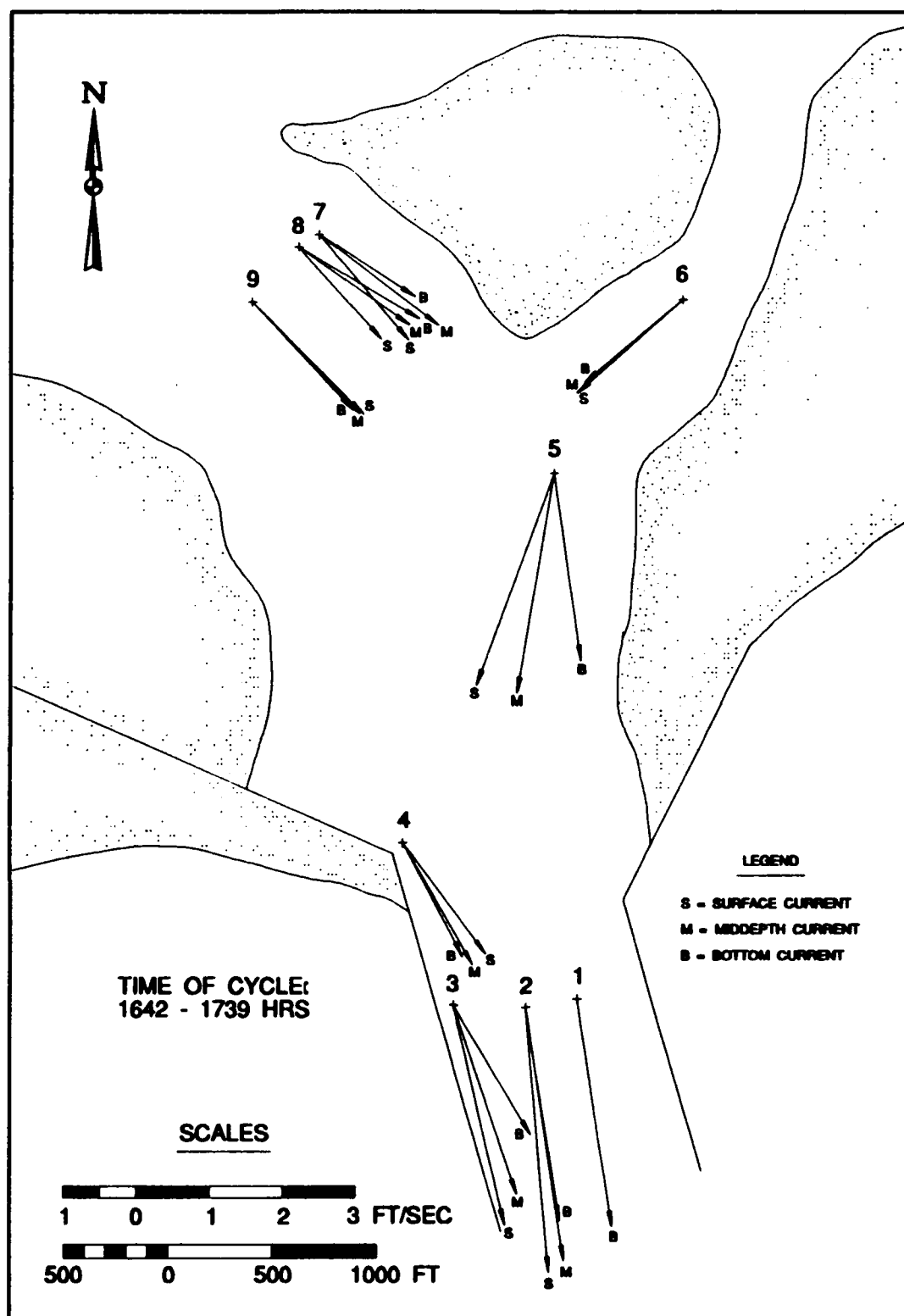


Figure 29. Tidal current data collected from 1642 to 1739 hr

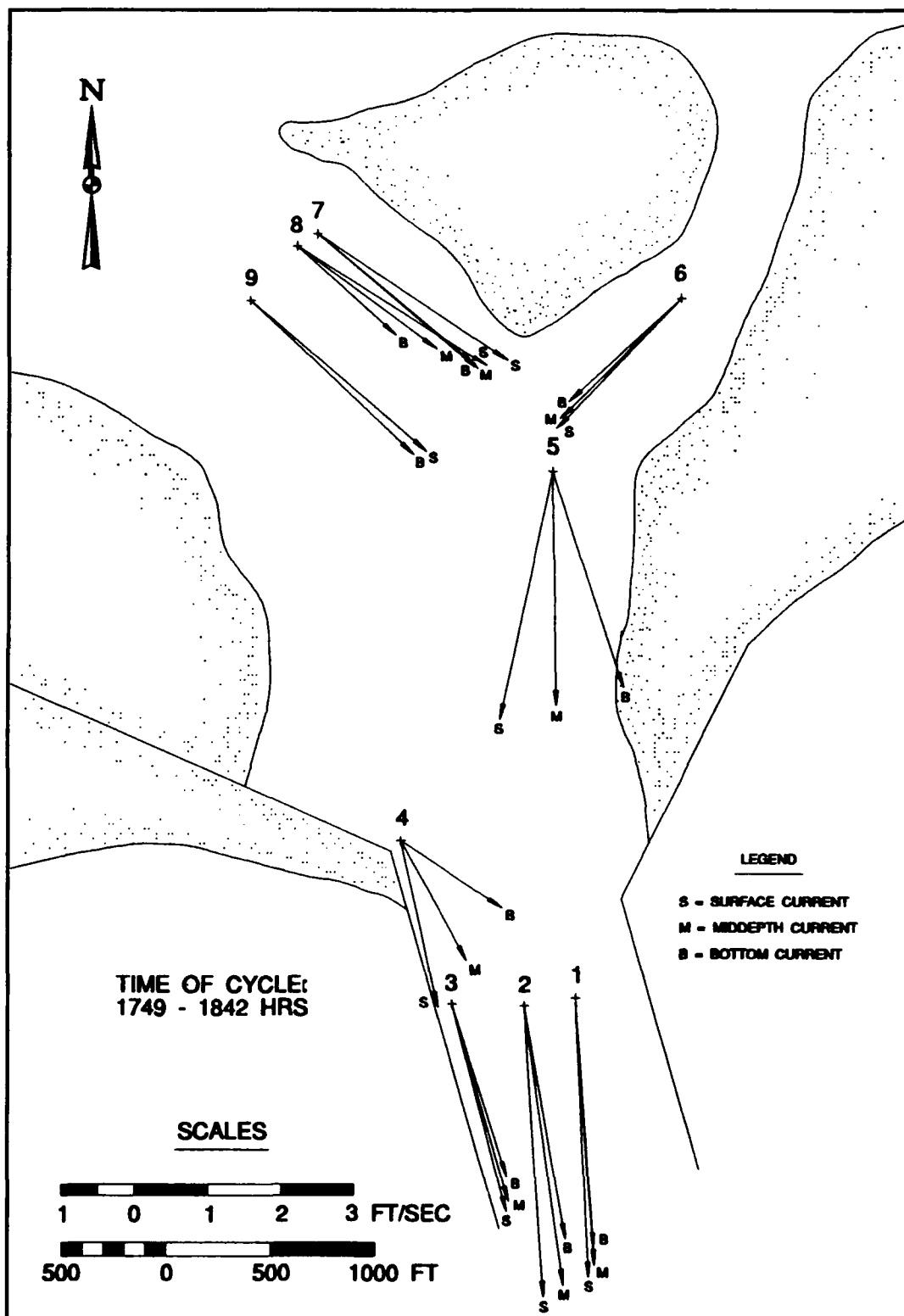


Figure 30. Tidal current data collected from 1749 to 1842 hr

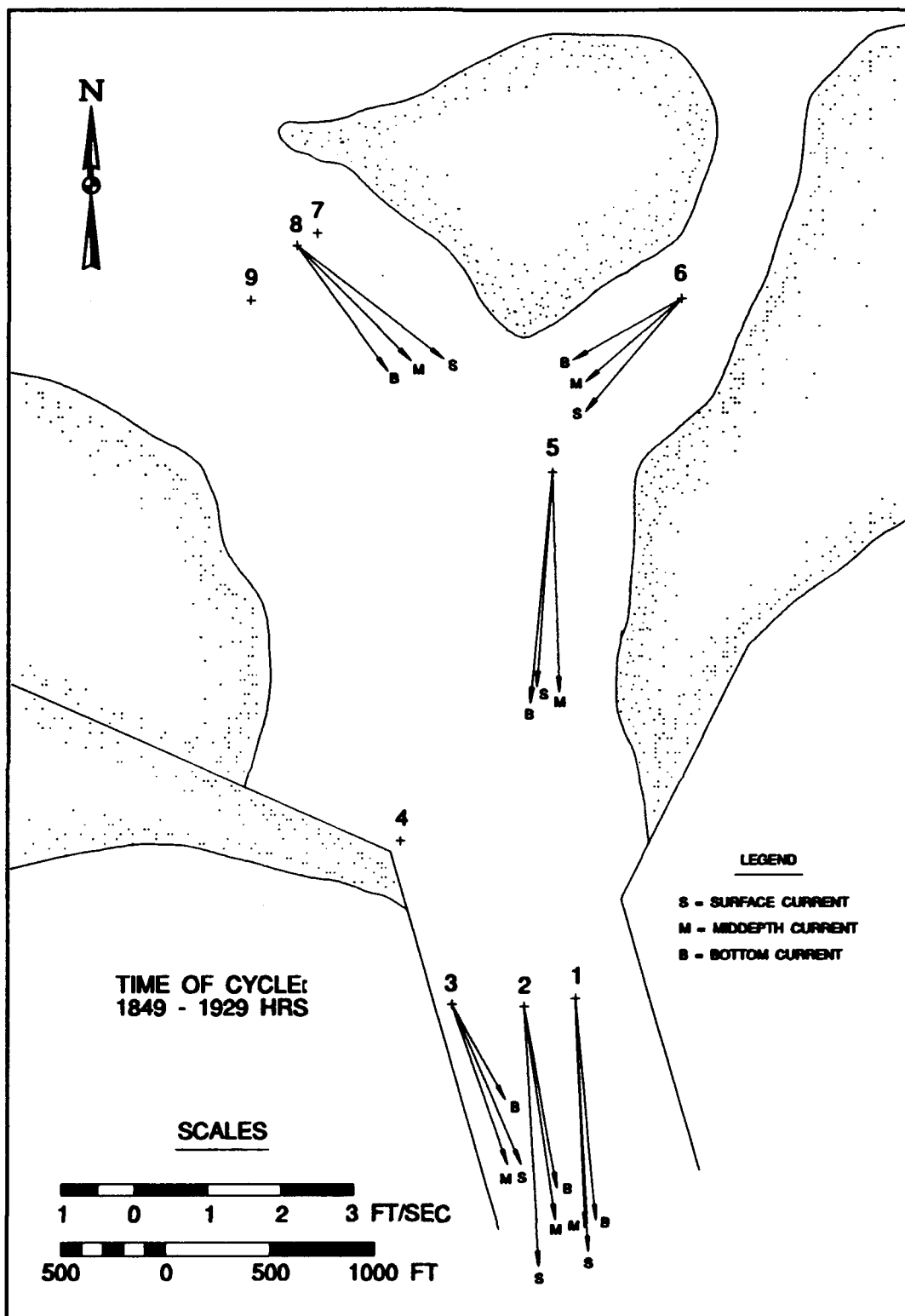


Figure 31. Tidal current data collected from 1849 to 1929 hr

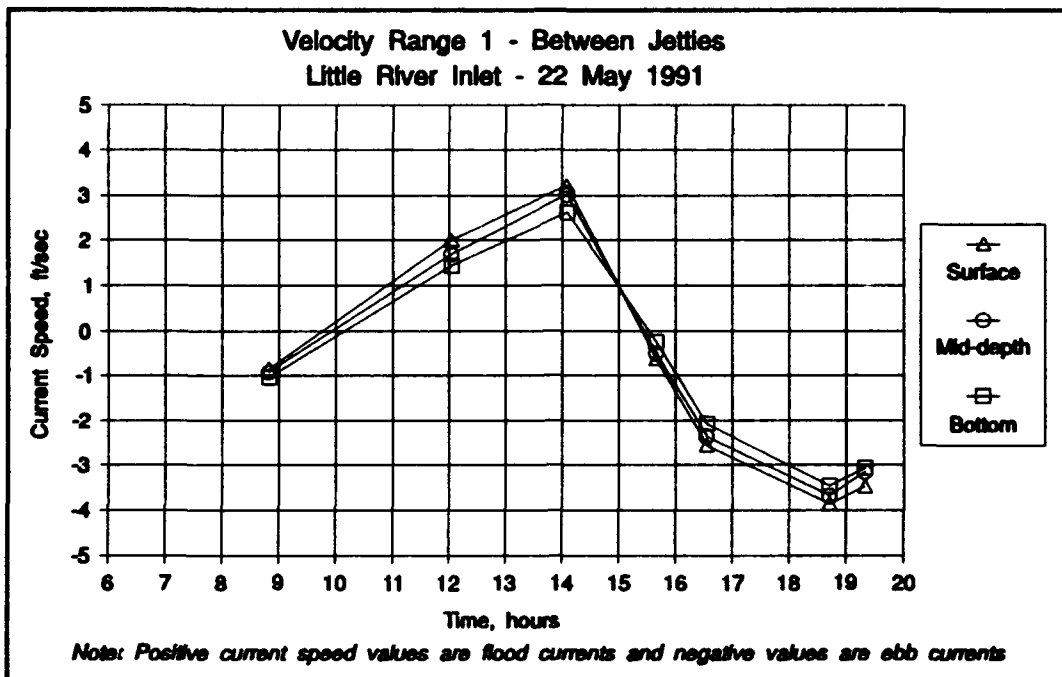


Figure 32. Current speeds over monitoring period for Station 1

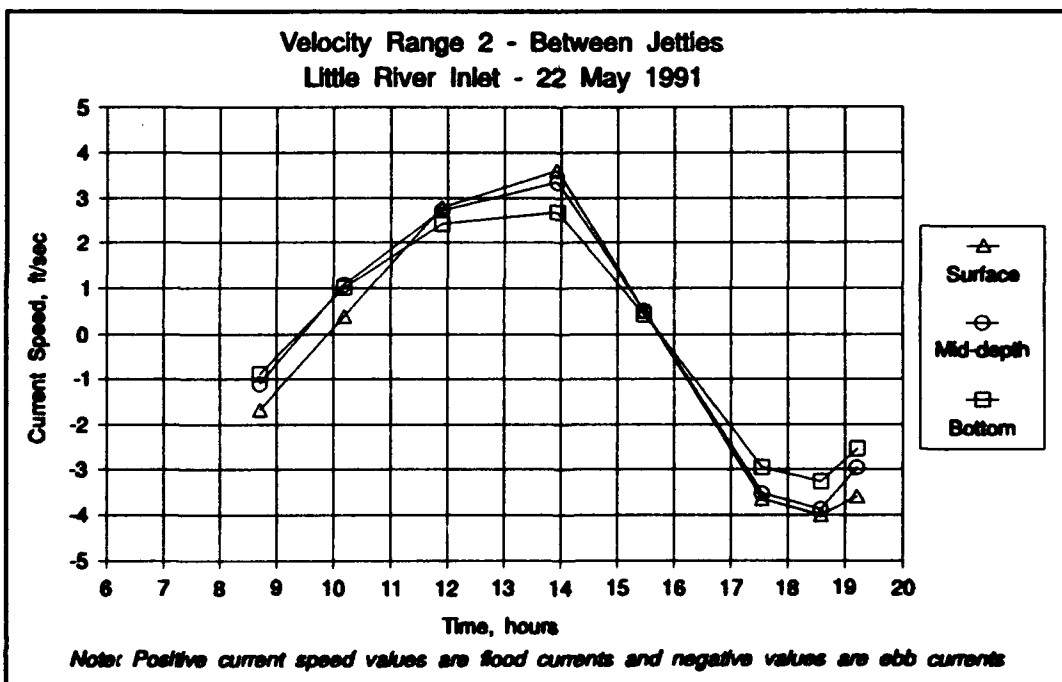


Figure 33. Current speeds over monitoring period for Station 2

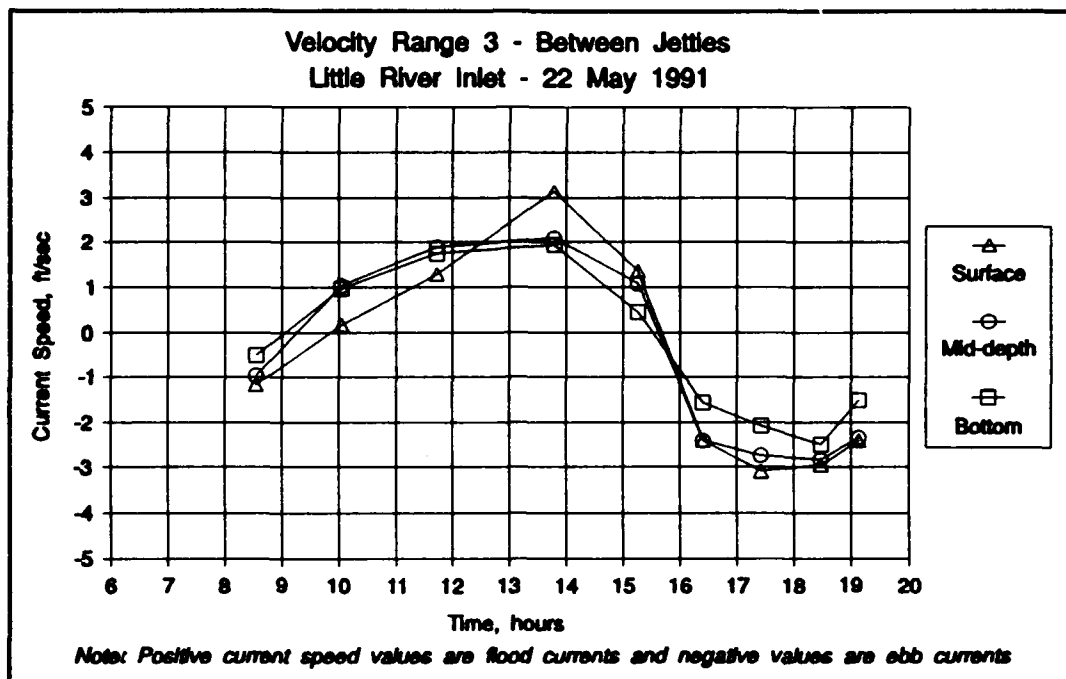


Figure 34. Current speeds over monitoring period for Station 3

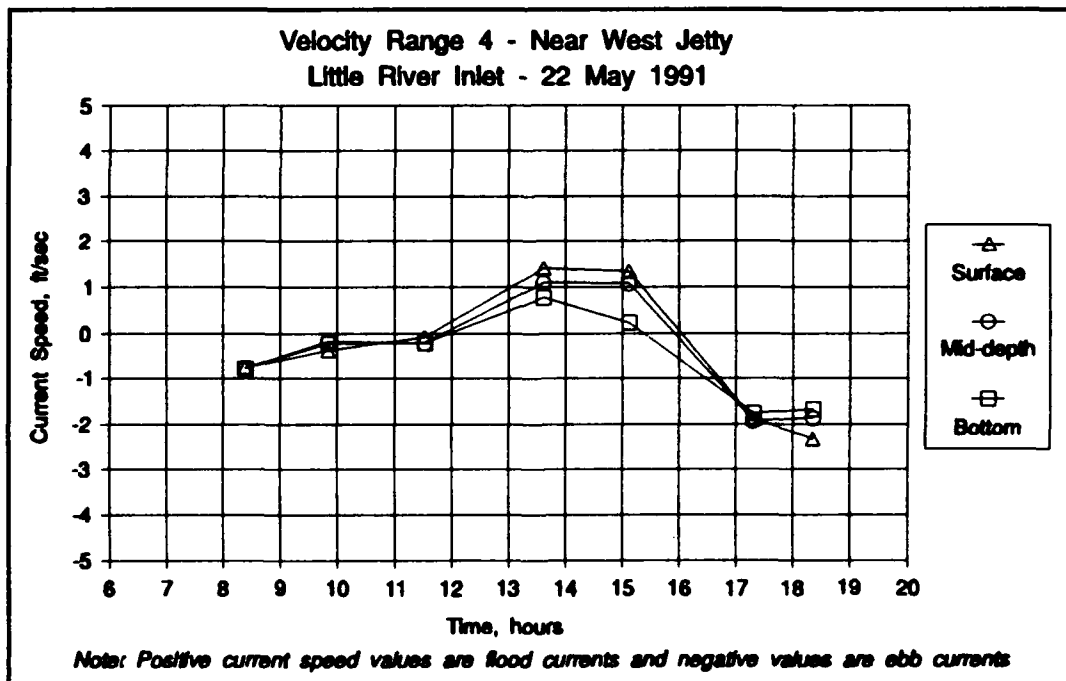


Figure 35. Current speeds over monitoring period for Station 4

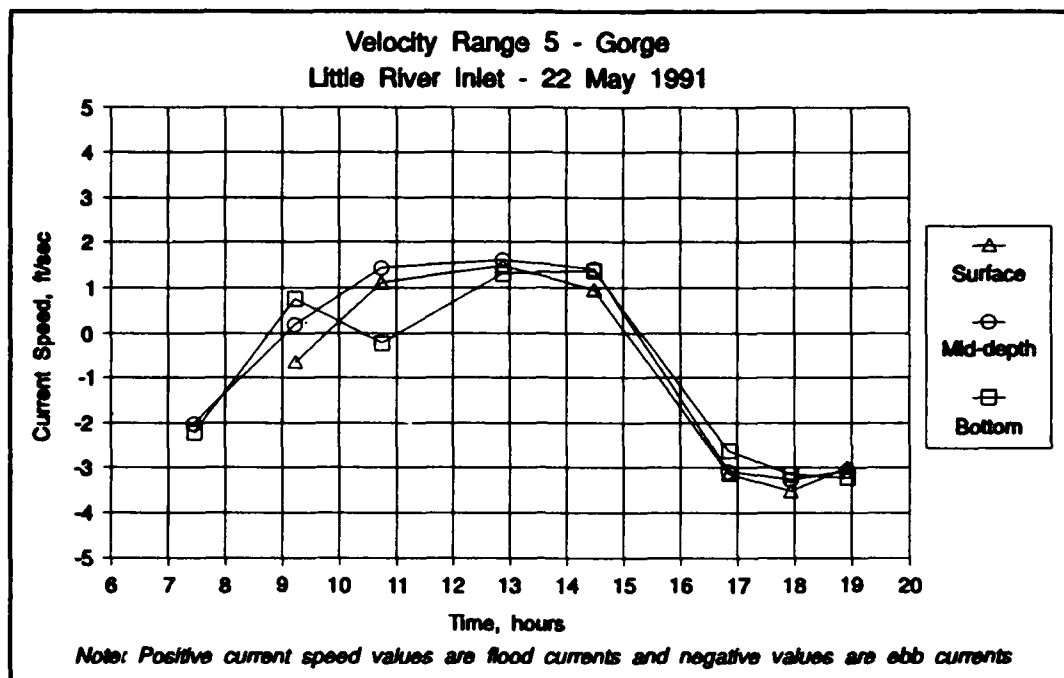


Figure 36. Current speeds over monitoring period for Station 5

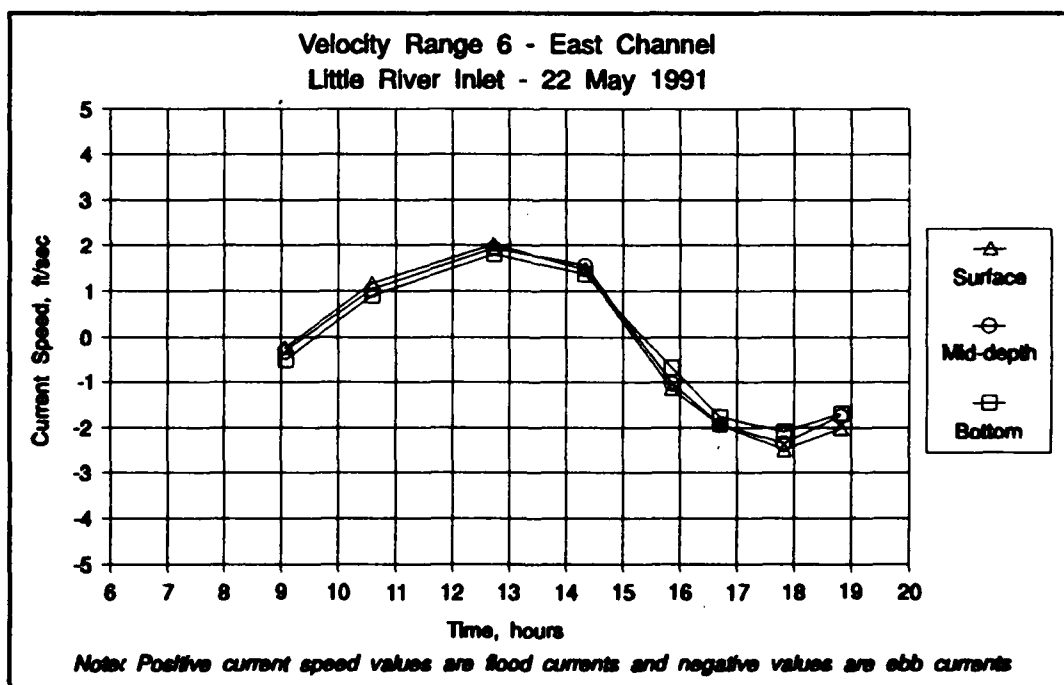


Figure 37. Current speeds over monitoring period for Station 6

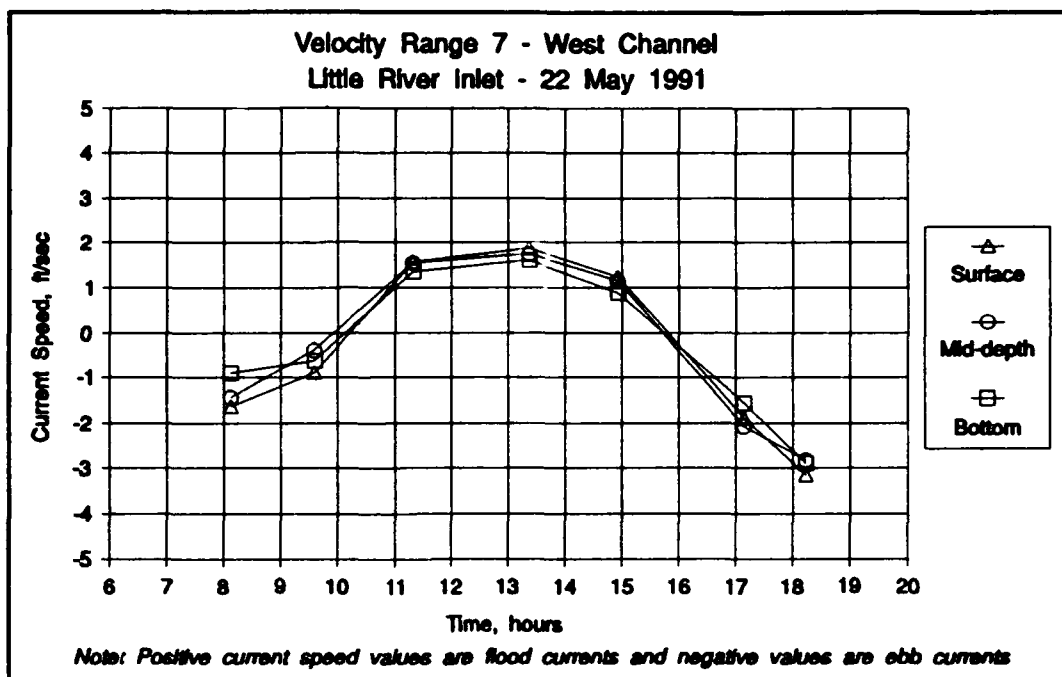


Figure 38. Current speeds over monitoring period for Station 7

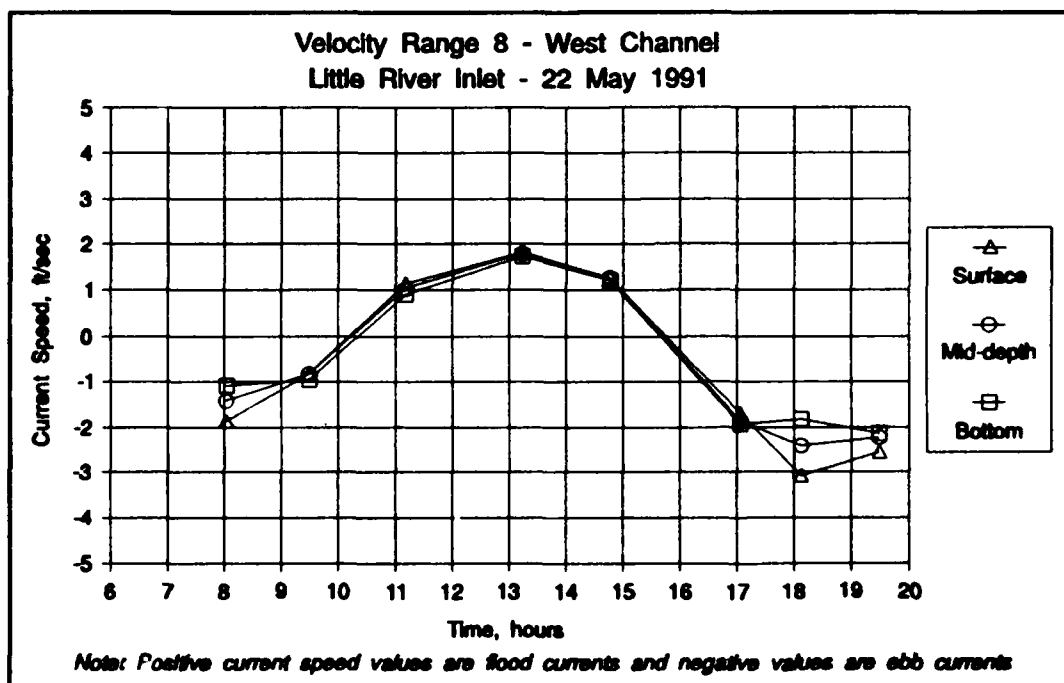


Figure 39. Current speeds over monitoring period for Station 8

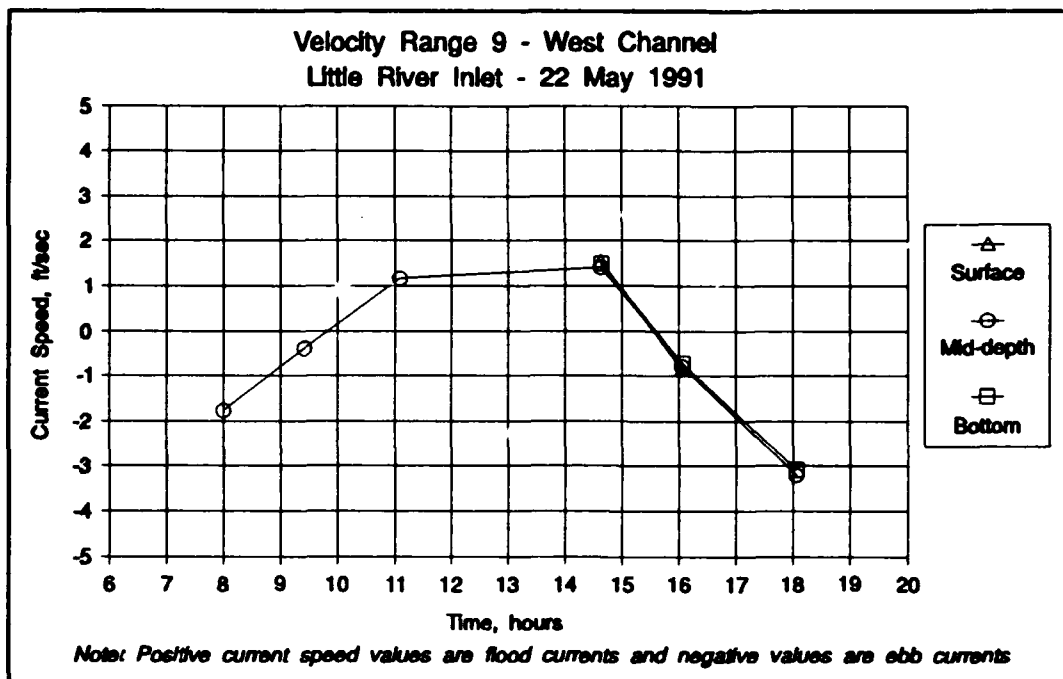


Figure 40. Current speeds over monitoring period for Station 9

Side-scan sonar survey

36. A side-scan sonar survey of the west jetty was conducted during slack tide on 23 May 1991, using SAC's Klein Model "Hydroscan" side-scan sonar equipment. This system can be operated at either 100 or 500 kHz. The side-scan survey was conducted to qualitatively assess the jetty's condition, to identify any dislocations of armor stone, and to potentially delineate the spatial distribution of various bedforms and sediment types through the inlet. Severe wave conditions prohibited a survey of the east jetty tip.

37. Four side-scan runs were made along the length of the west jetty. A run consisted of operating the boat at a constant speed, 75 to 150 ft off of the jetty structure. During the run, marks were made on the records at known locations along the structure. Positioning of the boat during data collection, however, was largely uncontrolled, thus the interpreted data can be considered only reconnaissance level. Summaries of the side-scan surveys and analysis are presented in Appendix A.

Review of the Physical Model Study

38. A fixed-bed model study of Little River Inlet was conducted by the Waterways Experiment Station for the Charleston District prior to project construction (Seabergh and Lane 1977). This study was performed to assist in planning and design of jetty structures, and included an investigation of items such as optimum jetty alignment, length and spacing, current patterns and magnitudes, sediment tracer movement patterns on a fixed bed, and the effects on tidal prism.

39. A review of the physical model study was conducted, focusing on comparison of model results (including point velocities and surface current patterns) and pre-construction prototype velocity data with data collected in the May 1991 field study. This review and data interpretation helped describe the evolution of velocity patterns and provided an improved understanding of the Little River Inlet system.

40. The physical model study was performed with a fixed-bed tidal model built at a scale of 1:300 horizontally and 1:60 vertically. The model was constructed with 1974 prototype bathymetry, and velocities and tidal elevations were verified with prototype data collected in April 1974. The model was operated with a 5-ft tidal range which is very close to the tide range measured in the 1991 field data collection of currents and tides. This provided a good basis for comparing and contrasting model versus prototype velocities.

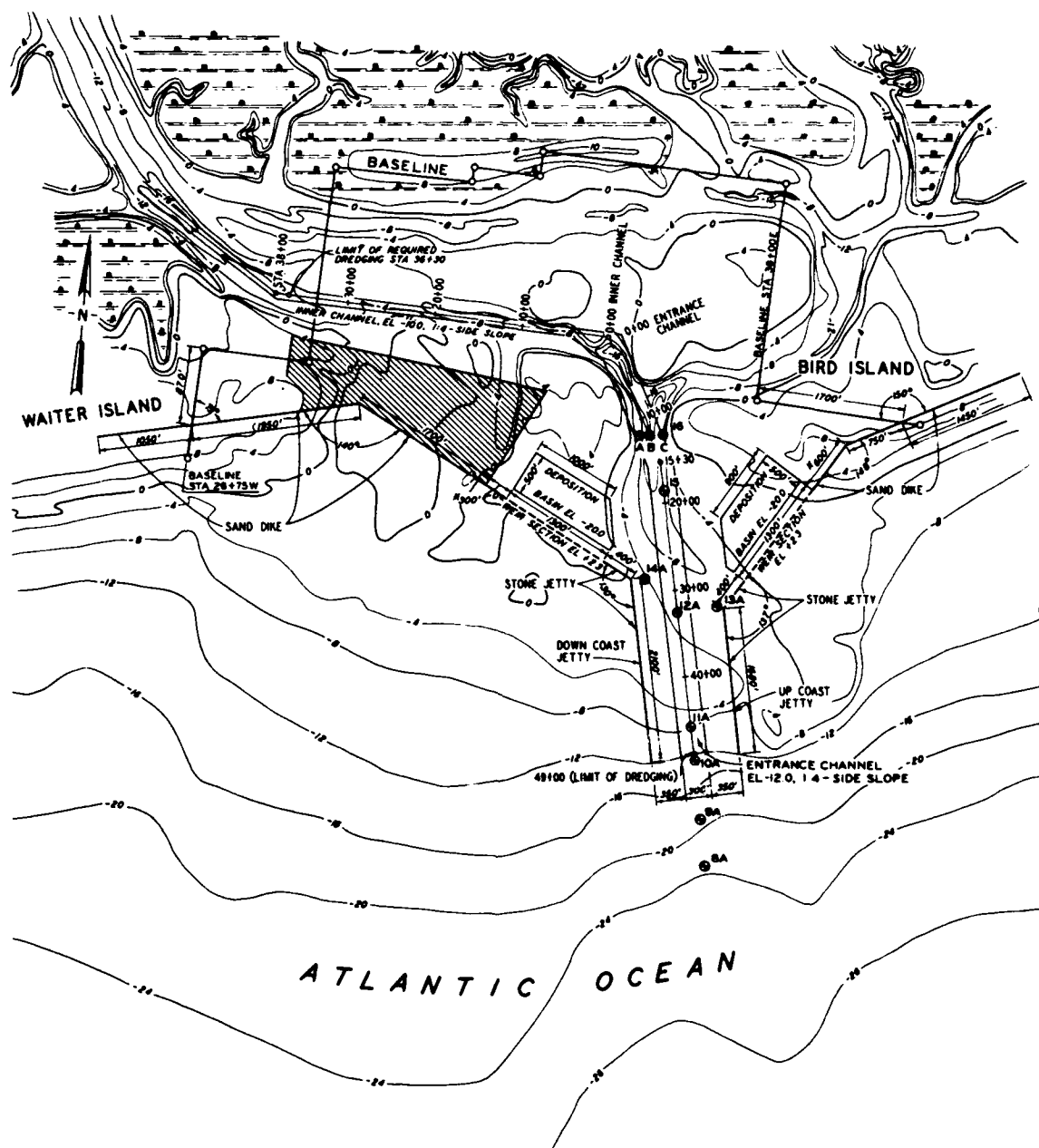
41. Initial model tests examined three basic project configurations. Two of these had four variations, where mean tide level weir jetties were incorporated into both jetties; the west jetty only; the east jetty only; and finally a no-weir option. The no-weir option was identified as Plan 2A in the model study report and is very similar to the as-constructed project except that the jetty lengths extended to the -12-ft MLW contour. The actual project jetties are shorter and extend to the -8-ft MLW contour. The initial study of configurations consisted primarily of collection of surface currents (described below) to aid in evaluating various plans. Plan 2D, which was selected for detailed tide and current measurements, had a weir in each jetty and the structures extended to -12-ft MLW. Therefore, the most directly comparable data is surface current data of Plan 2A; however, point velocity

data collected for Plan 2D can be used for comparisons with certain conditions discussed later.



Alignment of currents between jetties

42. The physical model bottom contours (1974 bathymetry) have a southeasterly trend in the region oceanward of the inlet gorge; that is, as the parallel jetty section is approached, contours swing toward the east jetty (Figure 41). This is in contrast to the general trend of a southwesterly orientation of contour alignment during prototype construction in 1981 and 1982 (see Figures 6 and 7). This variation of channel alignment also can be seen in a historical perspective (Figure 42). From periodic aerial photography between the late 1930's to the mid 1950's, it appears that the main ebb channel exited to the southeast (Figure 42a to 42d). The main channel then assumed a flow path nearly perpendicular to the shoreline (Figure 42e). By 1962, the channel assumed a southwesterly orientation (Figure 42f), and then rotated back to a somewhat southeasterly direction by 1970 (Figures 42g to 42j). Two years later, the channel had again oriented approximately perpendicular to the shoreline (Figure 42k).

43. Most likely, the orientation of bottom contours for the model study gave indications that ebb flow, as it approached the jetty system from the bay side, was slightly stronger along the east side of the entrance channel. Figure 43 shows velocities at Station 14A adjacent to the west jetty and Figure 44 shows velocities at Station 13A, adjacent to the bend in the east jetty. Ebb velocities (shown as negative values in the figures) are slightly higher and of longer duration at Station 13A (east side) when compared to Station 14A (west side). Also of interest is the comparison of velocities at model Station 14A and velocities at the May 1991 prototype Station 4 (see Figure 21). After adjusting the time of occurrence of prototype velocities relative to the tide stage, they were plotted against the model velocity curve in Figure 43. These velocities are nearly identical. The comparison indicates that velocity distribution across the channel may be tending to return to a state where flow is more centrally aligned between the jetties, as was observed in the model study. Evidently, the 1991 prototype velocities are relatively low, and must have been higher to cause scour along the west jetty. It should be noted that point velocities in the model were collected for a dual-weir jetty system. Weir elevations were at mean tide level, so that after the tide fell to mean tide level all ebb velocities were concentrated in



LEGEND

 FILL AREA
 VELOCITY STATION LOCATION

NOTE: CONTOURS ARE IN FEET REFERRED TO MLW
APRIL 1974 SURVEY

* STEP UP ON 1:25 SLOPE TO EL.+8.0 AND
EXTEND WEIR INTO SAND DIKE.

SCALE IN FEET

0 500 1000

Figure 41. Jetty and channel alignment for Plan 2D
(from Seabergh and Lane 1977)



MAR. 25, 1938



JAN. 23, 1945



DEC. 30, 1949



NOV. 30, 1954



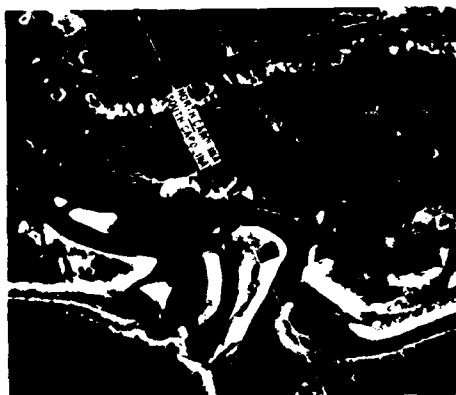
OCT. 10, 1958



APR. 4, 1962

SCALE
2000 0 2000 4000 FT
[Scale bar with tick marks]

Figure 42. Little River Inlet, 1938-1974
(from Seabergh and Lane 1977) (Continued)



FEB. 21, 1963



FEB. 26, 1966



DEC. 4, 1969



MAR. 27, 1970



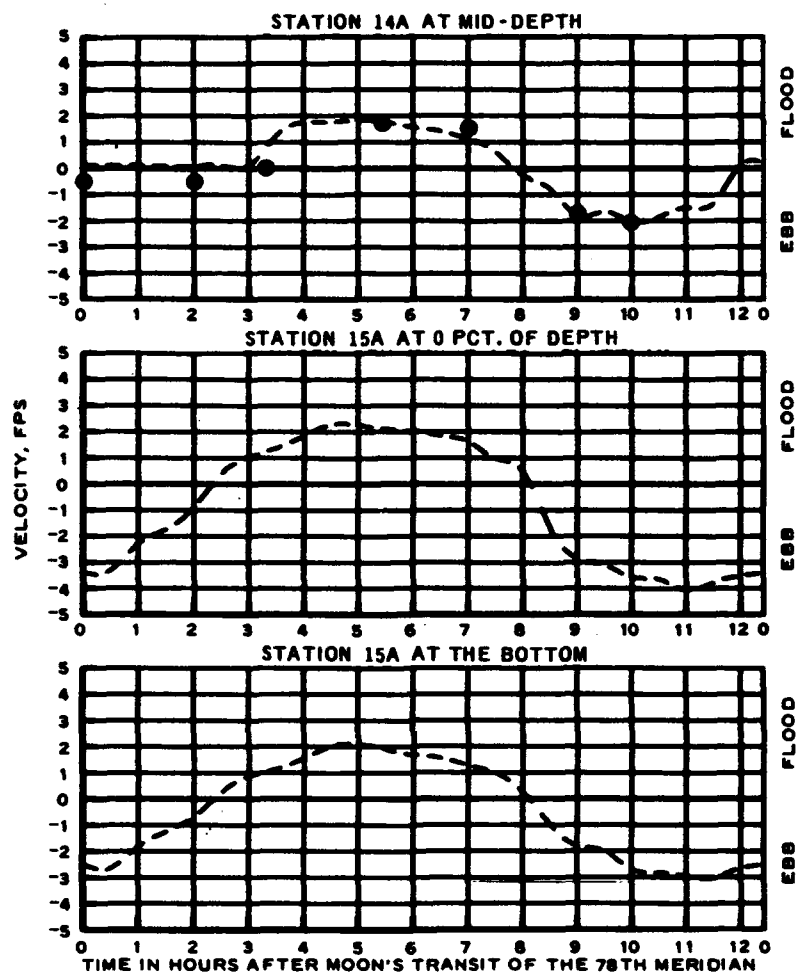
DEC. 17, 1972



MAR 19, 1974

SCALE
2000 0 2000 4000 FT

Figure 42. (Concluded)

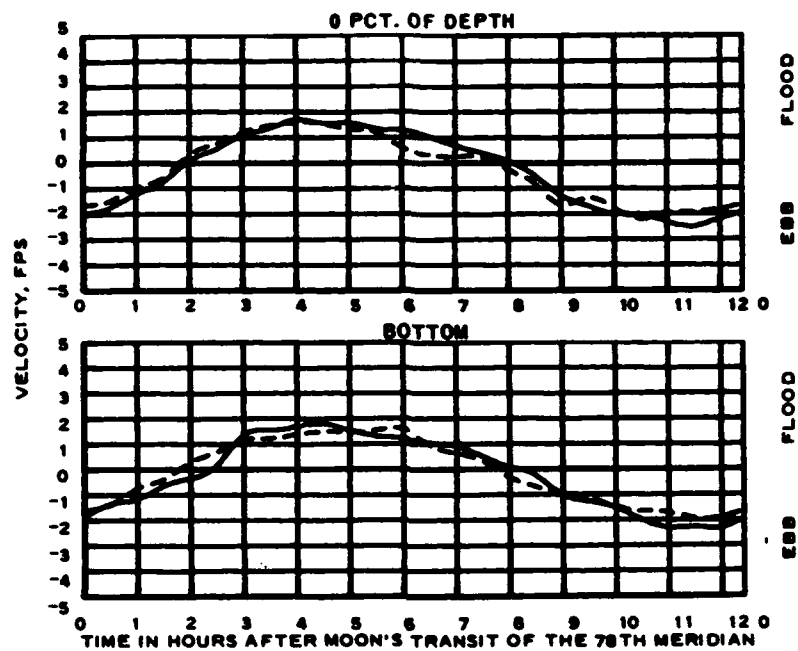


TEST CONDITIONS
OCEAN TIDE RANGE = 5.0 FT

LEGEND
— BASE
--- PLAN 2D
● RANGE 4 PROTOTYPE DATA
22 MAY 91

**EFFECTS OF PLAN 2D
ON VELOCITIES**
STATION
14A, 15A, AND 15A

Figure 43. Effects of Plan 2D on velocities (from Seabergh and Lane 1977)



TEST CONDITIONS
 OCEAN TIDE RANGE = 5.0 FT
 2D = PLAN 2D WITH JETTIES EXTENDED TO THE -12 FT CONTOUR
 2D1 = PLAN 2D WITH JETTIES EXTENDED TO THE -8 FT CONTOUR

LEGEND
 — PLAN 2D
 - - - PLAN 2D1

**EFFECTS OF REDUCING
 JETTY LENGTHS
 ON VELOCITIES**
 STATIONS
 13A

Figure 44. Effects of reducing jetty lengths on velocities
 (from Seabergh and Lane 1977)

the region between the jetties. Thus, it may be assumed that the ebb velocity distribution in the channel after mean tide level is reached should be similar for either open or closed weirs.

44. Surface current photographs were taken in the model for a condition where the weirs were closed (Plan 2A), so these results can be used for a direct comparison to the existing prototype system. Figure 45 shows ebb flow during maximum currents. The length of the streak, created by a 4-sec exposure of white styrofoam floats, can be scaled to a prototype velocity by the scale included with the photograph. Surface currents on the west side of the channel parallel the structures. Ebb currents on the east side approaching the parallel jetties region have a slight directional change toward the east jetty, then curve to the center of the channel once in between the jetties. Thus, the ebb surface current velocities indicate a slight trend to deflect toward the east jetty.

45. Maximum surface currents measured between the jetties for Plan 2A (both weirs closed) in the model were 4.0 to 4.3 ft/sec during ebb flow, and 3.3 to 4.2 ft/sec during flood flow. These can be compared to maximum surface currents measured in the 1991 field study where the maximum surface ebb current between the jetties was measured as 4.0 ft/sec at Station 2 (see Figure 21) and the maximum surface flood current was 3.6 ft/sec, again at Station 2. The good agreement of model-prototype velocities helps to validate the use of the model data for qualitative comparisons, remembering comparisons must be made carefully due to differences in the 1991 prototype bathymetry and the model's 1974 bathymetric configuration.

Flow at jetty tips

46. Flood flow surface currents indicate a concentration of flow at the jetty tips (Figure 46) which illustrates a probable mechanism for scour at these locations. The larger scour on the east jetty tip may be due to a combination of tidal currents and wave-generated longshore currents moving on the seaward side of the east jetty and parallel to it, then combining with the flood tidal currents. Also, wind-driven currents occurring during north-easters may flow parallel to the shore toward the jetty system and concentrate in the vicinity of the jetty tip. The model study only considered tidal current effects in the surface current tests. It is of interest to examine flood surface currents for Plan 2D1, which has the shortened, as-constructed jetty length, but includes two weirs. Using the surface current photo at



Figure 45. Physical model study showing ebb flow during maximum currents
(after Seabergh and Lane 1977)



Figure 46. Physical model study showing concentration of flood flow at the jetty tips (after Seabergh and Lane 1977)

hour 4 (Figure 47), before the tide is high enough to begin flood flow over the weirs (a condition which can be compared to the existing prototype), a strong flow concentration is noted at the east jetty's seaward tip. Two hours later, the effect of the flood flow over the weirs can be noted (Figure 48), where velocities at the jetty tip are reduced significantly due to the increased flow area added by the weirs. The same trend is noted for velocities in the model channel.

Sediment movement

47. Examination of model testing with sediment tracers is not directly comparable to the prototype because all sedimentation type model tests were run with the two weir sections open. The duration of such tests were typically six tidal cycles so that the influence of the weir and its associated sediment basin usually removed a significant amount of sediment from the system. There were tests that indicated some movement of sediment around the east jetty tip and accumulation just inside, between the channel and the jetty (Figure 49).

48. Physical model results appear to support ongoing (1991) trends occurring in the prototype. According to the May 1991 field study results, ebb velocities approaching the parallel section of jetties are not concentrated along the west jetty, but are more centrally distributed across the channel. The initial prototype response concerning scour along the west jetty was not seen in the model study possibly due to the fact that the orientation of the natural channel and associated bathymetry had changed in the intervening eight years from the time of model bathymetry (1974) to the bathymetry during construction (1981 to 1983). Also, the prototype project was not constructed with functioning weirs, as was suggested by the model study. The use of weirs in jetties reduces velocities in the main entrance channel and possibly could have reduced scour in the channel and at the jetty tips. However, the use of weirs may have created problems with channel sedimentation and adjacent shoreline erosion, whereas no additional dredging or beach nourishment due to project-related erosion has been required thus far.



NOTE JETTIES EXTENDED TO
-H.M. CONTOUR

VELOCITY SCALE

1 0 1 2 3 4 5 6 7 8

FPS. PROTOTYPE

SCALES IN FEET

PROTOTYPE 300 0 300 600 900 1200 1500 1800

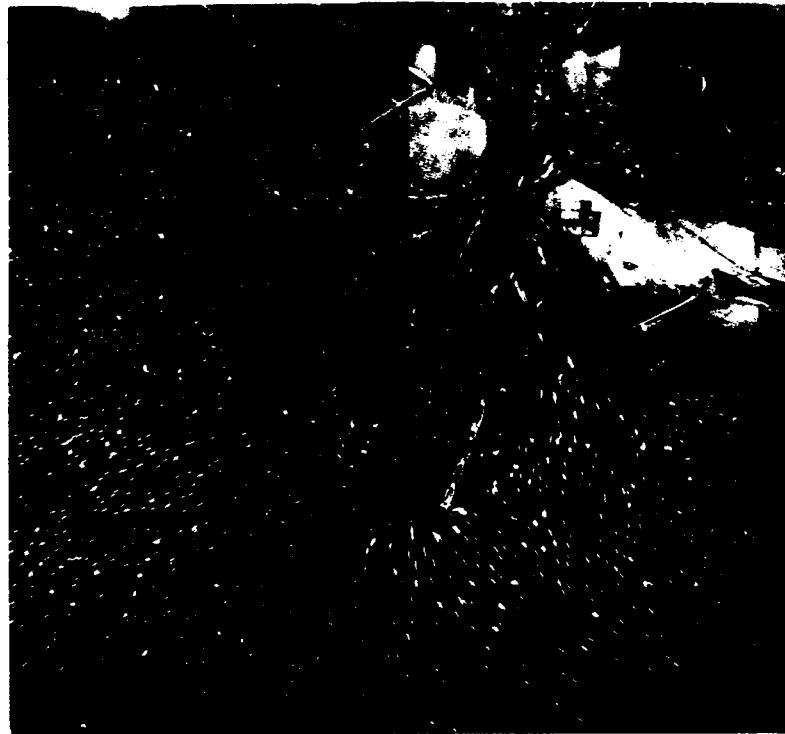
MODEL 18 IN PROTOTYPE 1:600 1:1200 1:1800 1:2400

SURFACE CURRENTS

1974 CONDITIONS
WITH PLAN 2-D1

FLOOD FLOW HOUR 4

Figure 47. Physical model study showing concentration of flood flow at east jetty tip (after Seabergh and Lane 1977)



NOTE: JETTIES EXTENDED TO
RAFT CONTOUR

VELOCITY SCALE

1 0 1 2 3 4 5 6 7 8

FPS, PROTOTYPE

SCALES IN FEET

PROTOTYPE 300 0 300 600 900 1200 1500 1800

MODEL 1/8" 0 1/8" 1/4" 3/8" 1/2" 5/8" 3/4"

SURFACE CURRENTS

1974 CONDITIONS
WITH PLAN 2-D1

FLOOD FLOW HOUR 6

Figure 48. Physical model study showing concentration of flow later in the flood cycle (after Seabergh and Lane 1977)

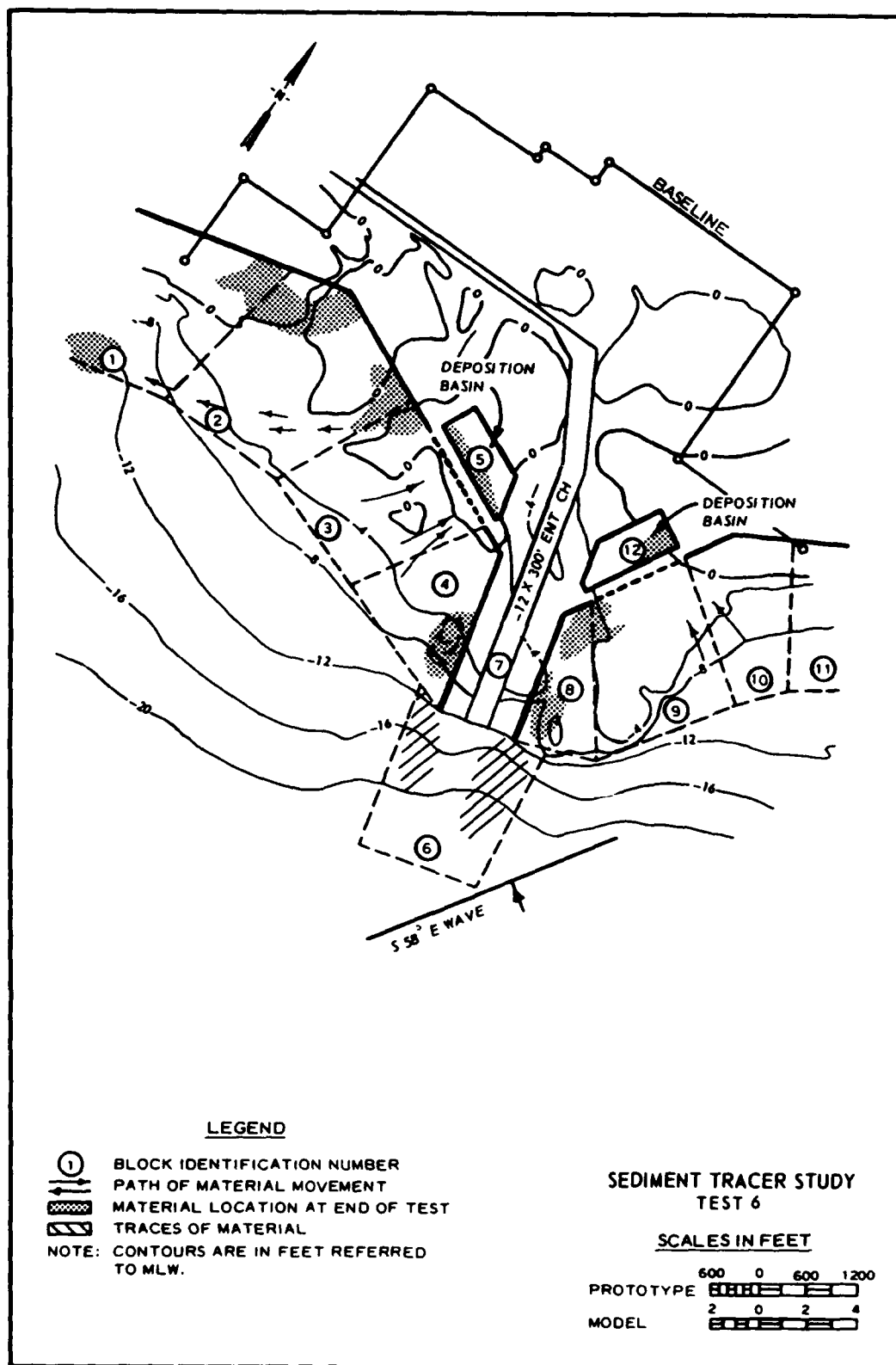


Figure 49. Results of the sediment tracer study
(from Seabergh and Lane 1977)

PART IV: SUMMARY OF DATA ANALYSIS

West Jetty Scour

49. Prior to stabilization of Little River Inlet, frequent shifting and migration of the barred channel and extensive shoals were typical of the inlet. At the time of west jetty construction, the dominant ebb channel was toward Waties Island and the southwest (see Figures 5 and 6). This dominant flow route was gradually modified as construction of the west jetty progressed, and the ebb tidal flow began channelizing along the inlet side of the west jetty (Figure 50; also see Figure 7). Additionally, the smaller east interior channel received a significant amount of tidal flow which circulated around the central flood shoal. The momentum of this flow may have helped to deflect the flow in the larger west interior channel toward the west jetty.

50. Construction of the west jetty was completed by July 1983. By the November 1983 condition survey, deepening along the west jetty on the order of 15 to 18 ft MLW had already begun to occur. Along Profile Line 31, which lies immediately east of the jetty (Figure 51), maximum depths of 20 to 25 ft MLW were evident at the jetty bend (Figure 52).

51. The dredging operation conducted in December 1983/ January 1984 utilized the dredged material as fill for the scour areas along the west jetty (Figure 53) and at the east jetty tip. However, this solution proved to be only temporary and the deepening trend continued at the west jetty bend and along the structure (Figures 54, 55, and 56). A significant scour hole at the west jetty tip is apparent in the June 1985 profile survey (Figure 54; see also Figure 9). The December 1989 profile survey (Figure 56; see also Figure 12) was taken approximately 2 months after Hurricane Hugo made landfall in the South Carolina region. It appears that the storm caused a substantial amount of erosion along the profile line; however, there has been some recovery of material along the majority of the jetty in more recent surveys (Figure 57; see also Figure 19).

East Jetty Scour

52. Profile Line 27, referred to in Figures 58 through 61, lies immediately to the west of the east jetty (see Figure 51). Scour at the east

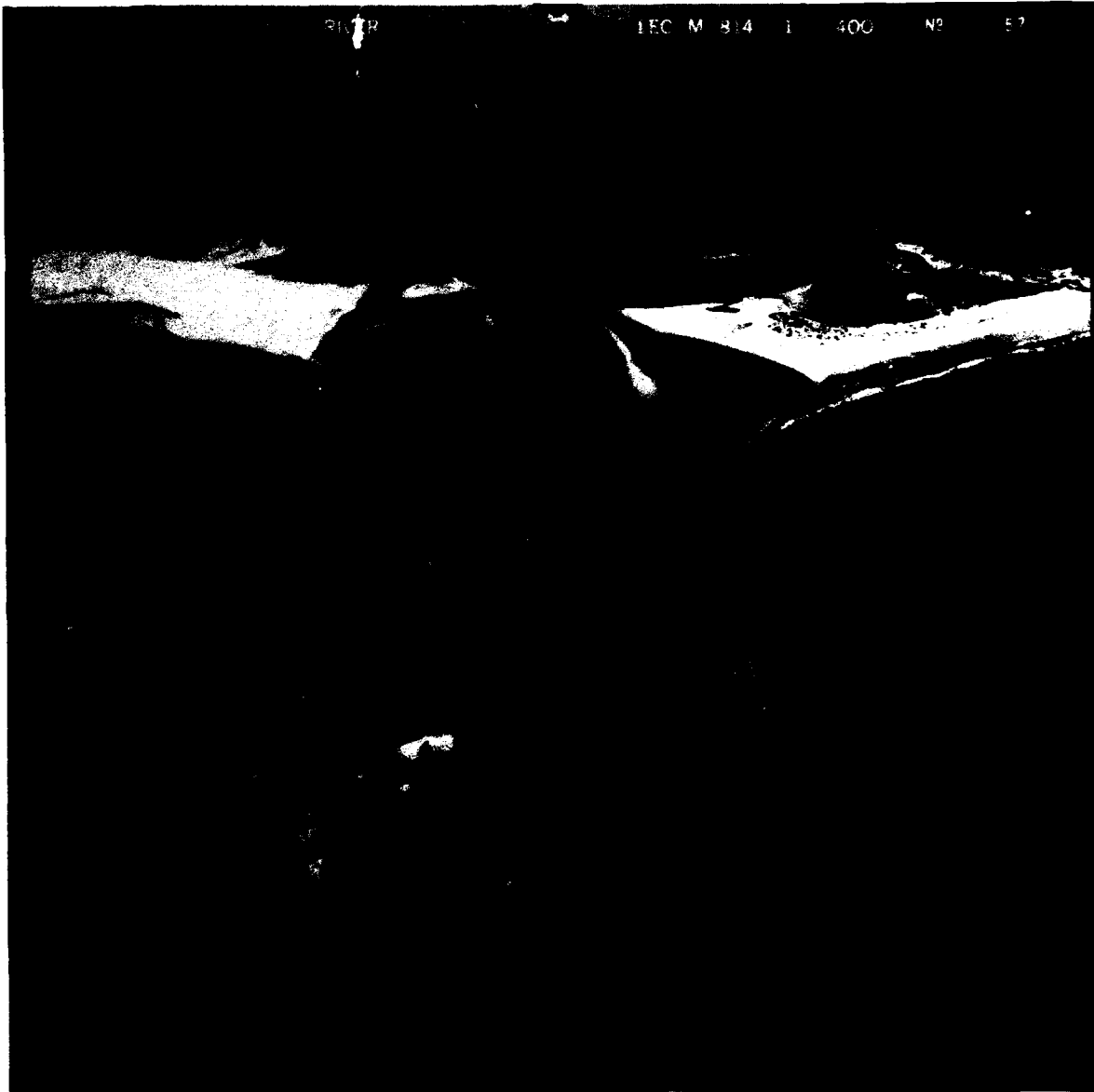


Figure 50. Aerial photography showing channel configuration during construction of the west jetty: September 1982

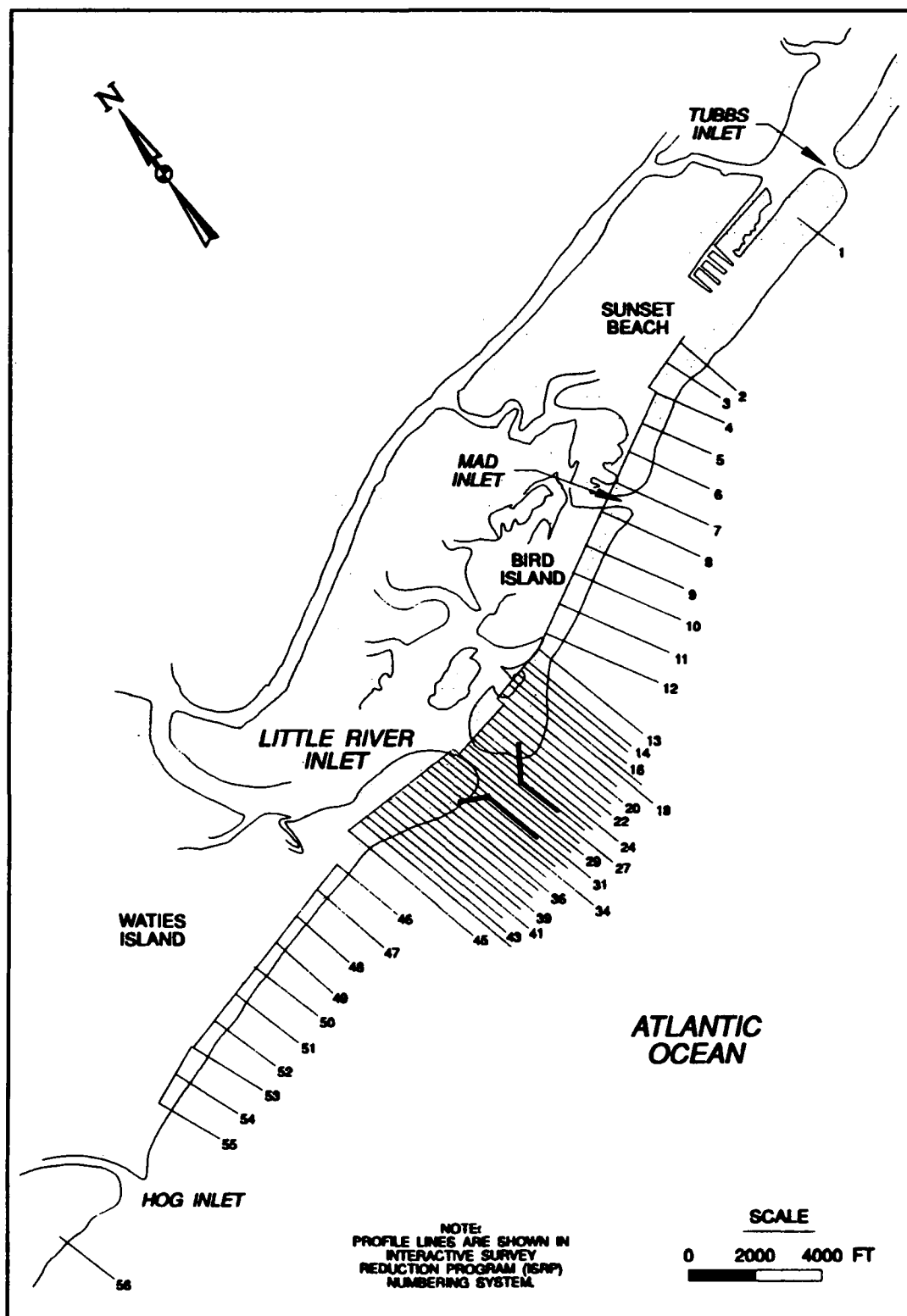


Figure 51. Little River Inlet profile lines

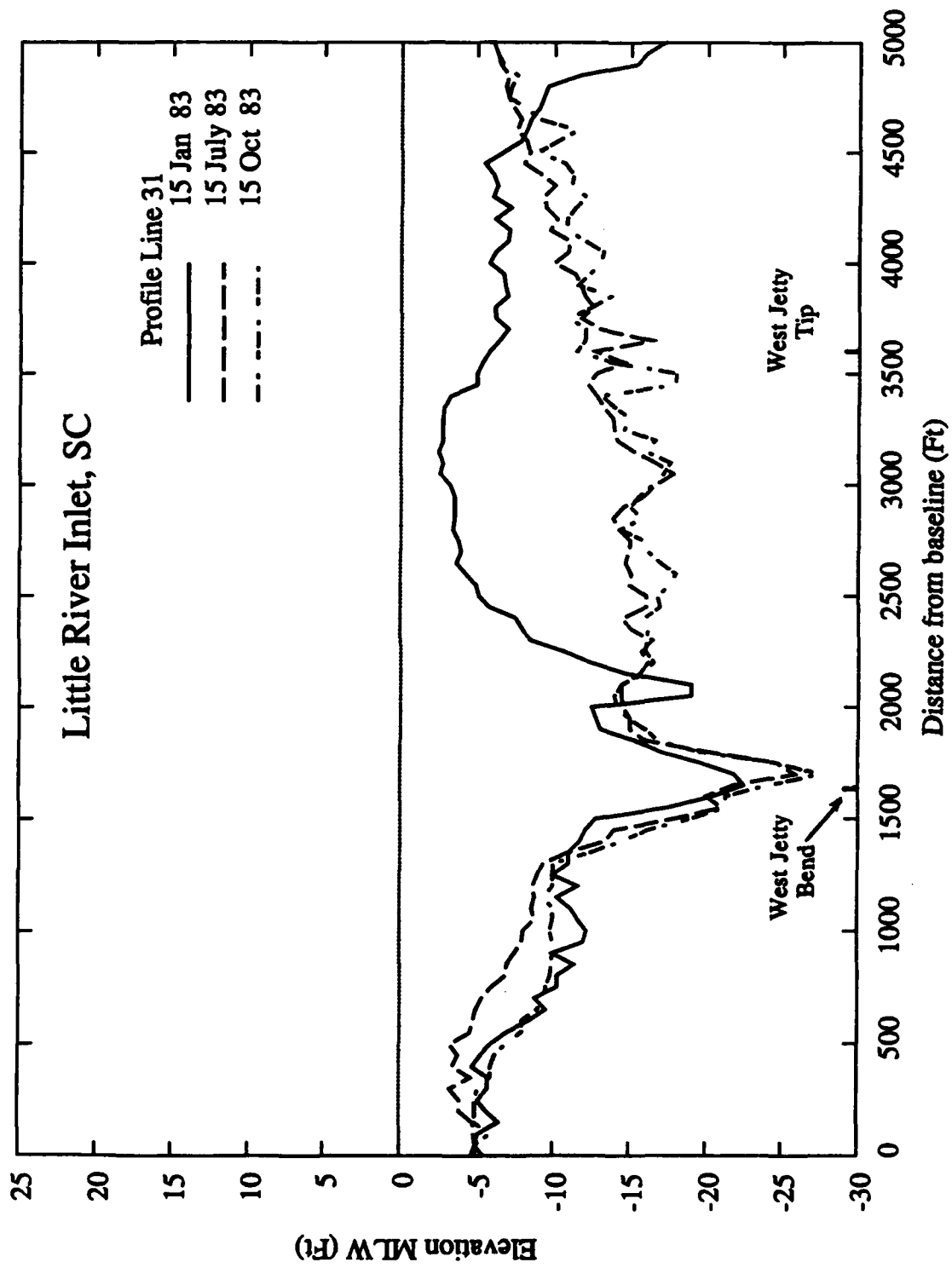


Figure 52. Profile along inside of west jetty: January to October 1983

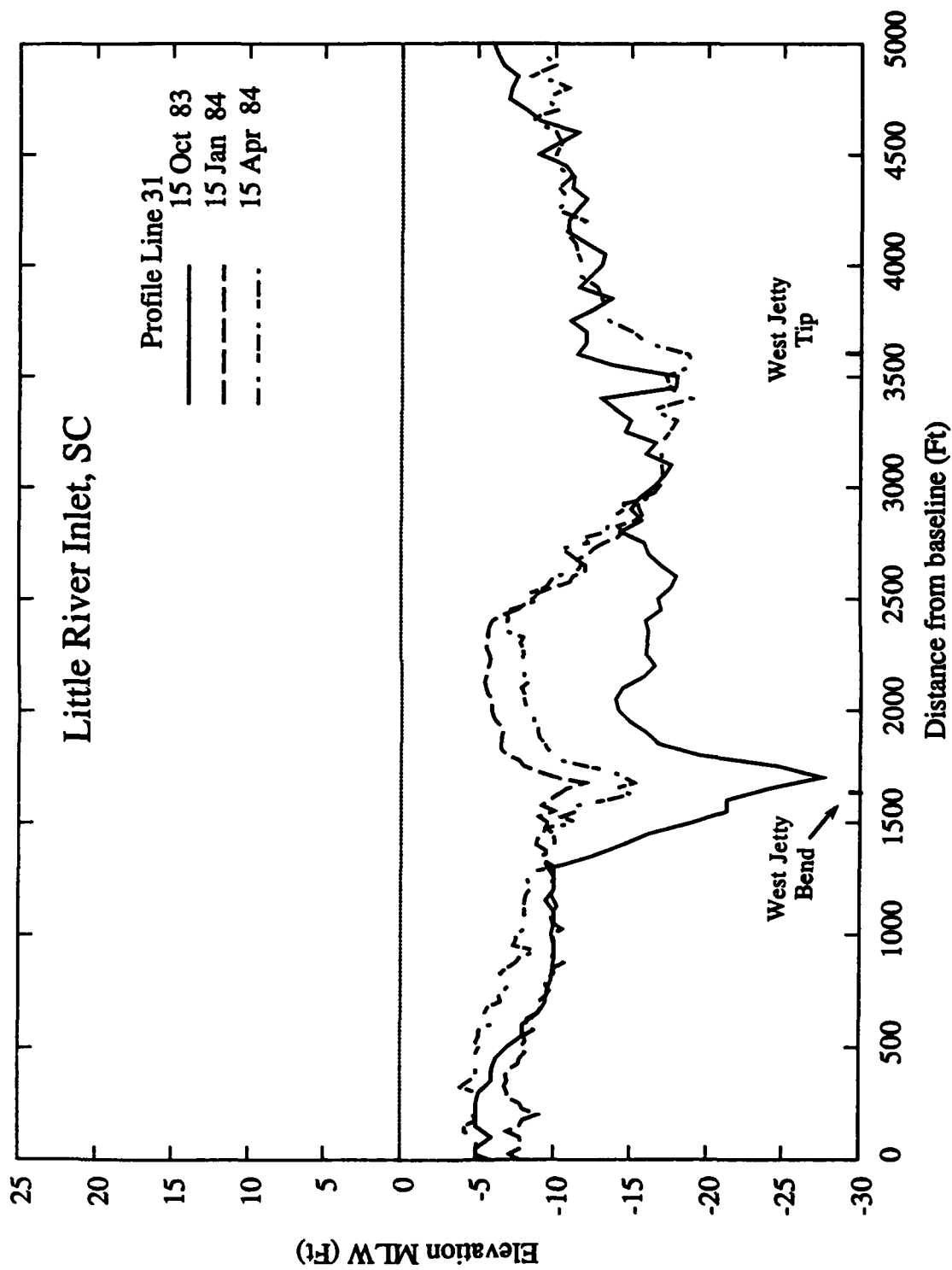


Figure 53. Profile along inside of west jetty: October 1983 to April 1984

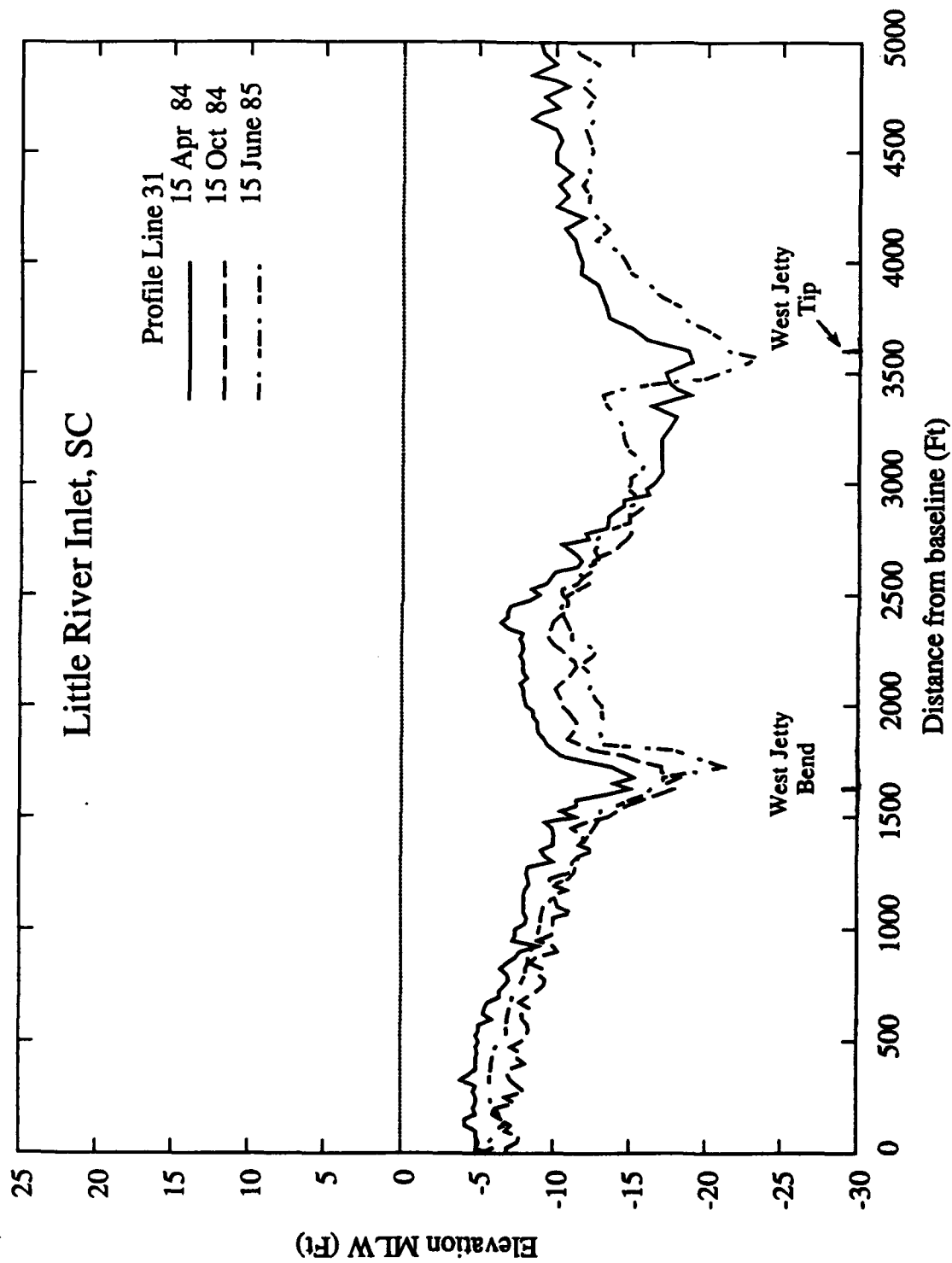


Figure 54. Profile along inside of west jetty: April 1984 to June 1985

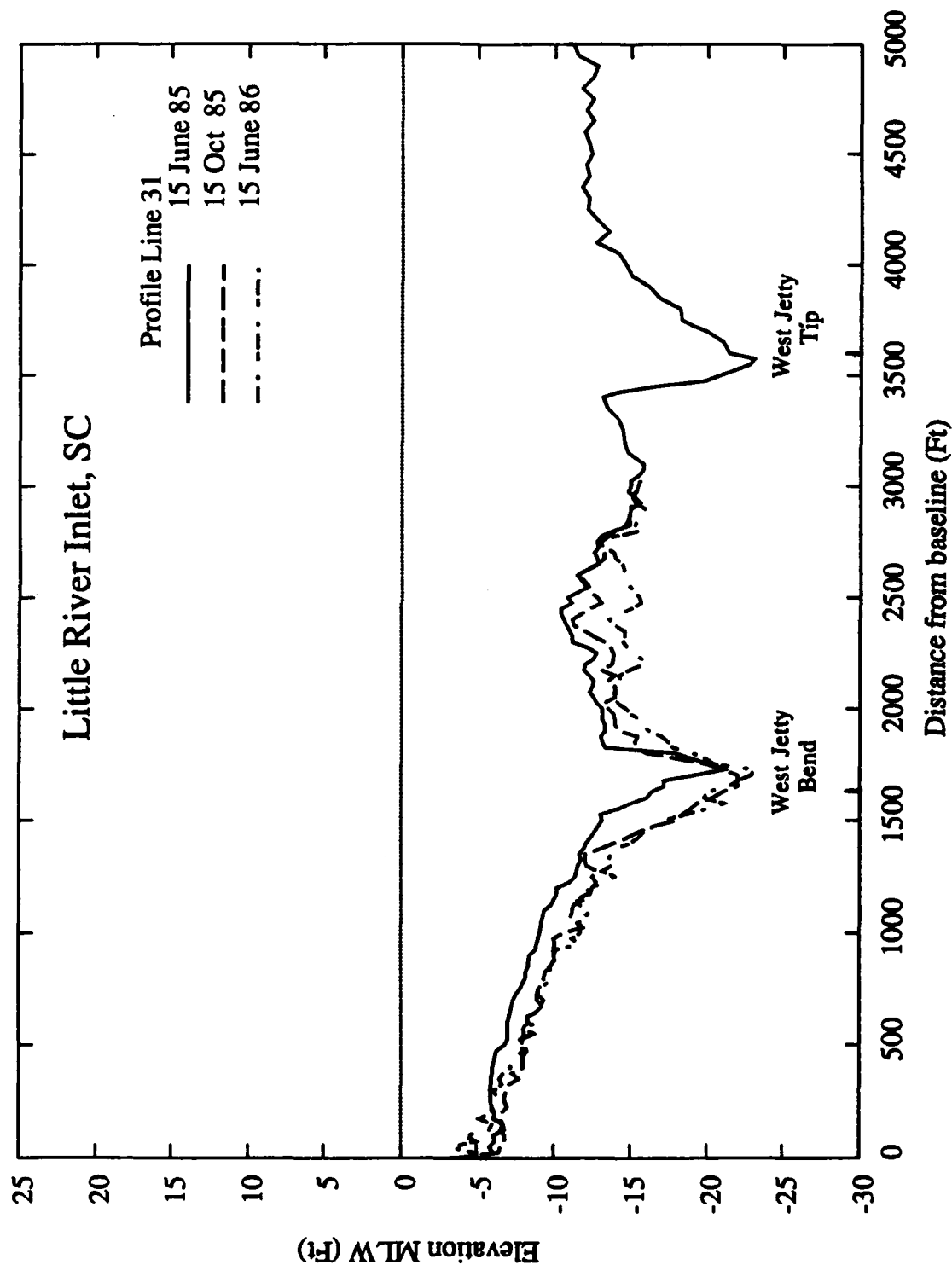


Figure 55. Profile along inside of west jetty: June 1985 to June 1986

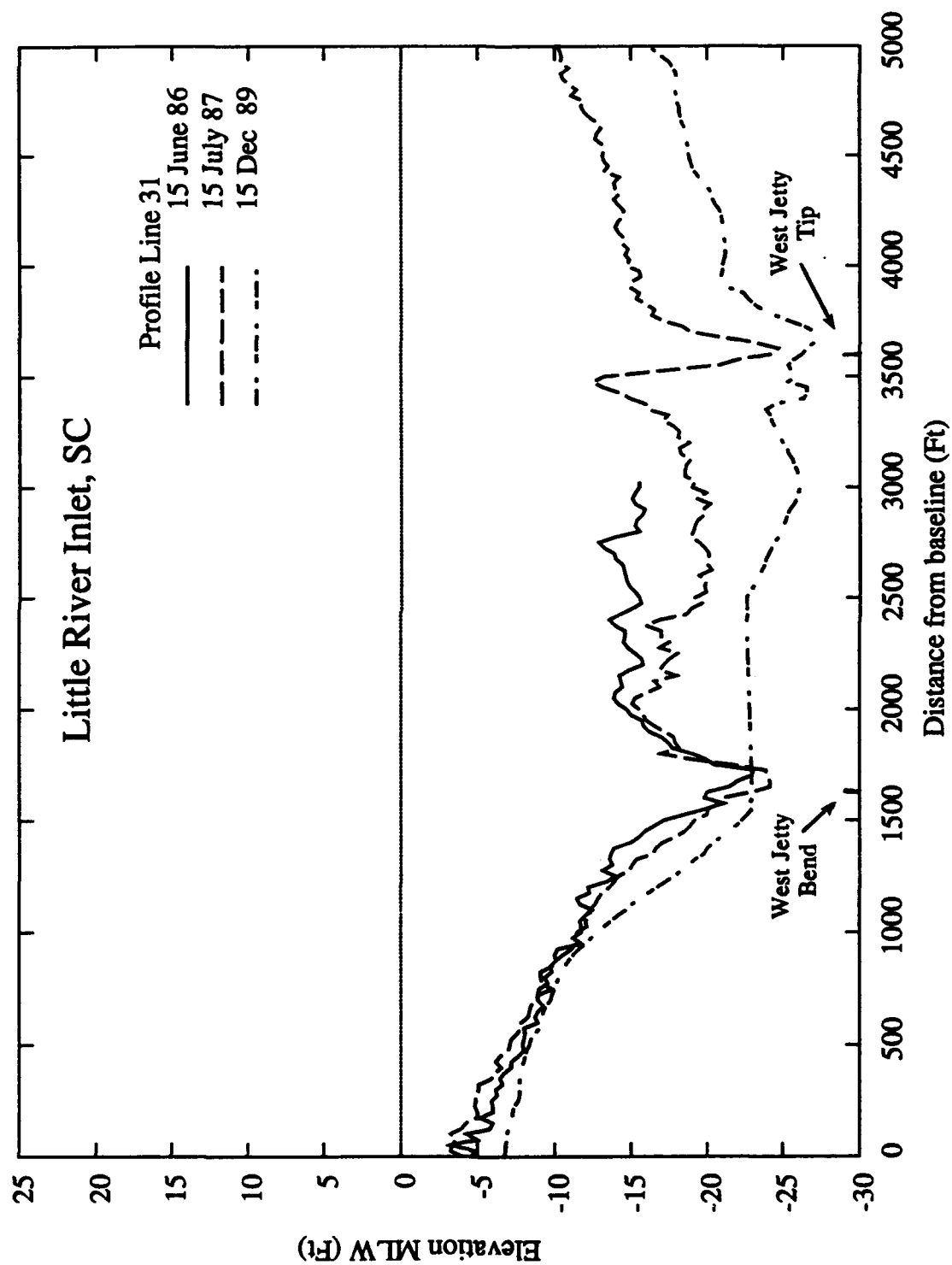


Figure 56. Profile along inside of west jetty: June 1986 to December 1989

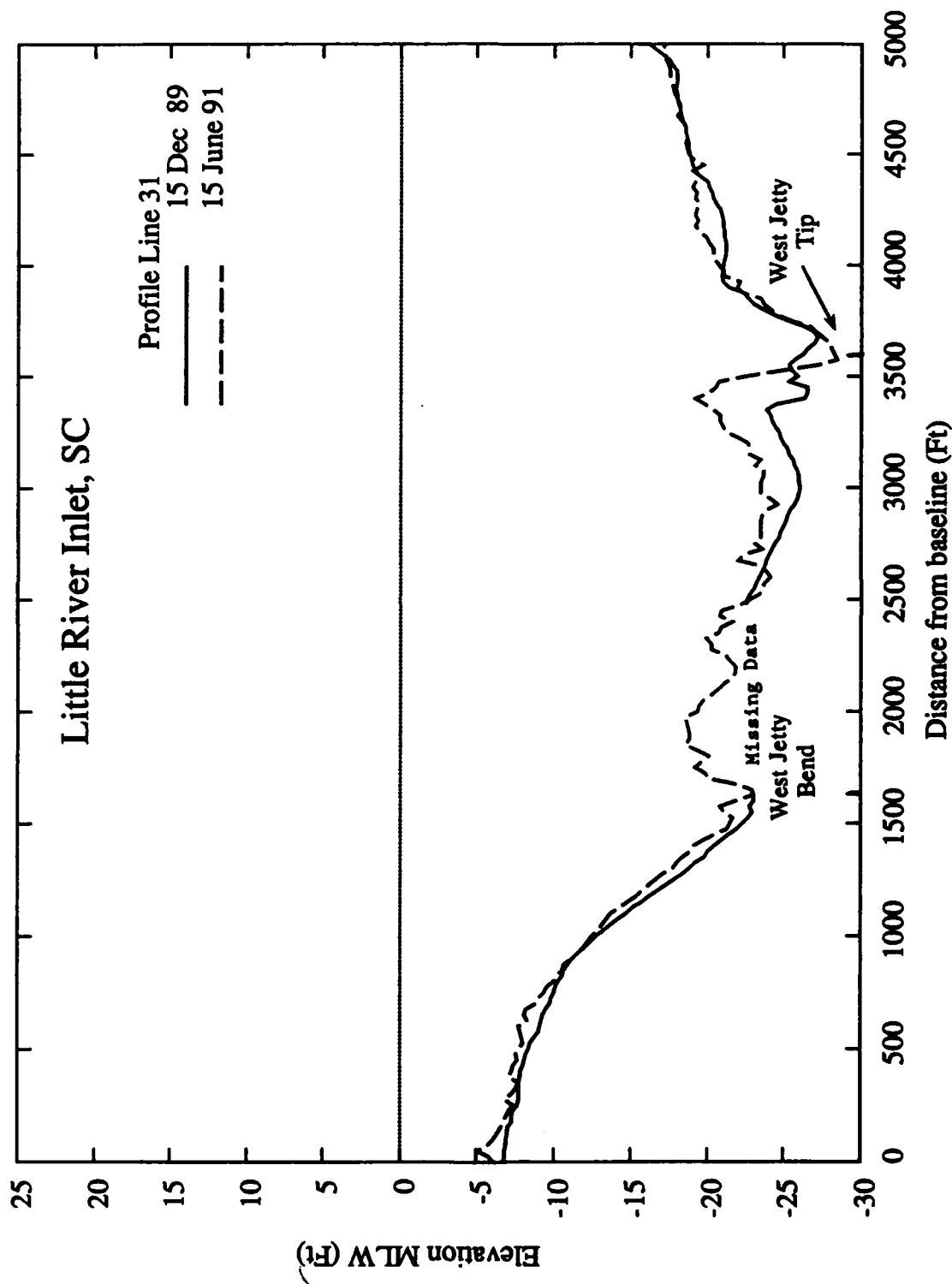


Figure 57. Profile along inside of west jetty: December 1989 to June 1991

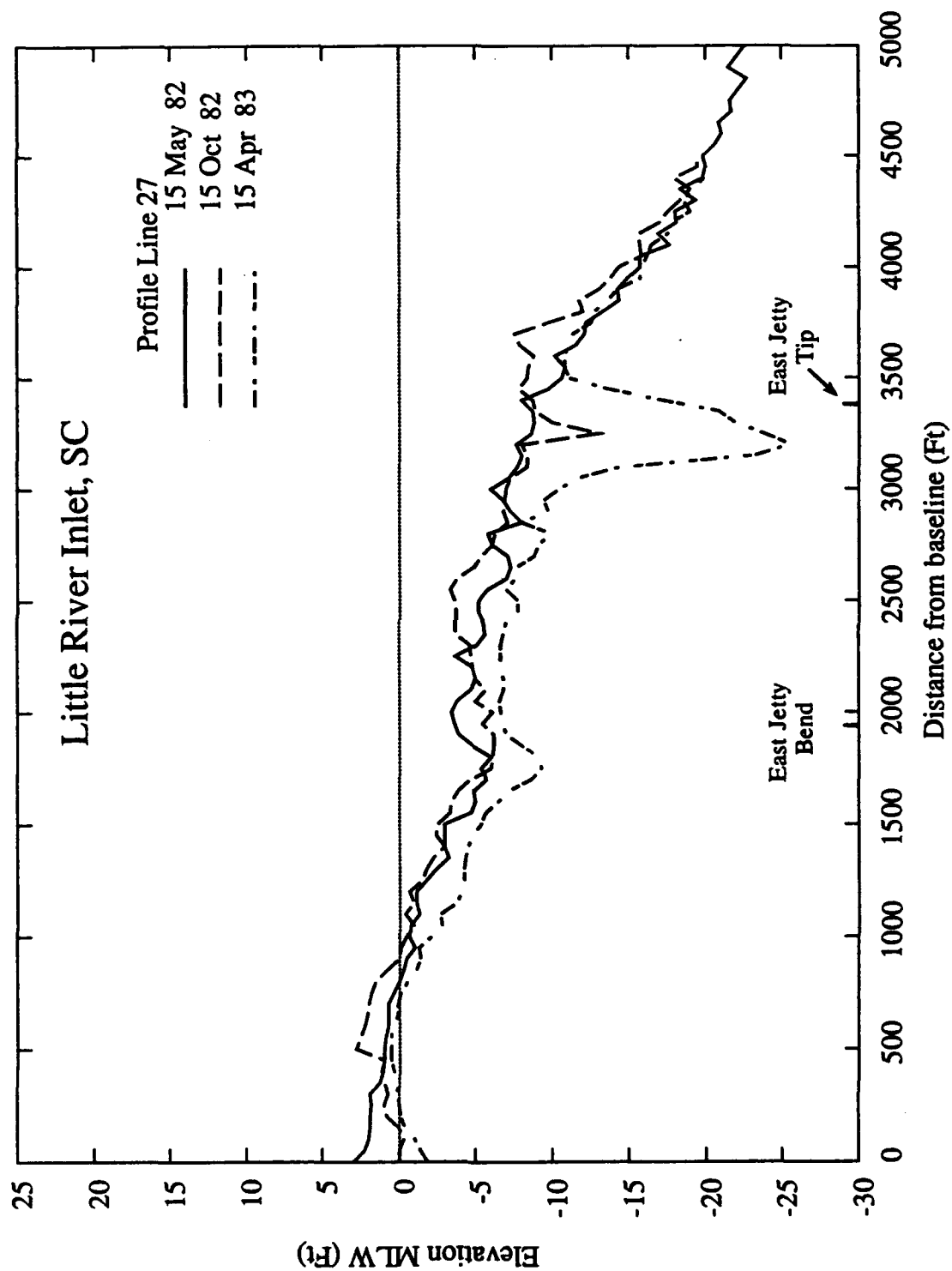


Figure 58. Profile along inside of east jetty: May 1982 to April 1983

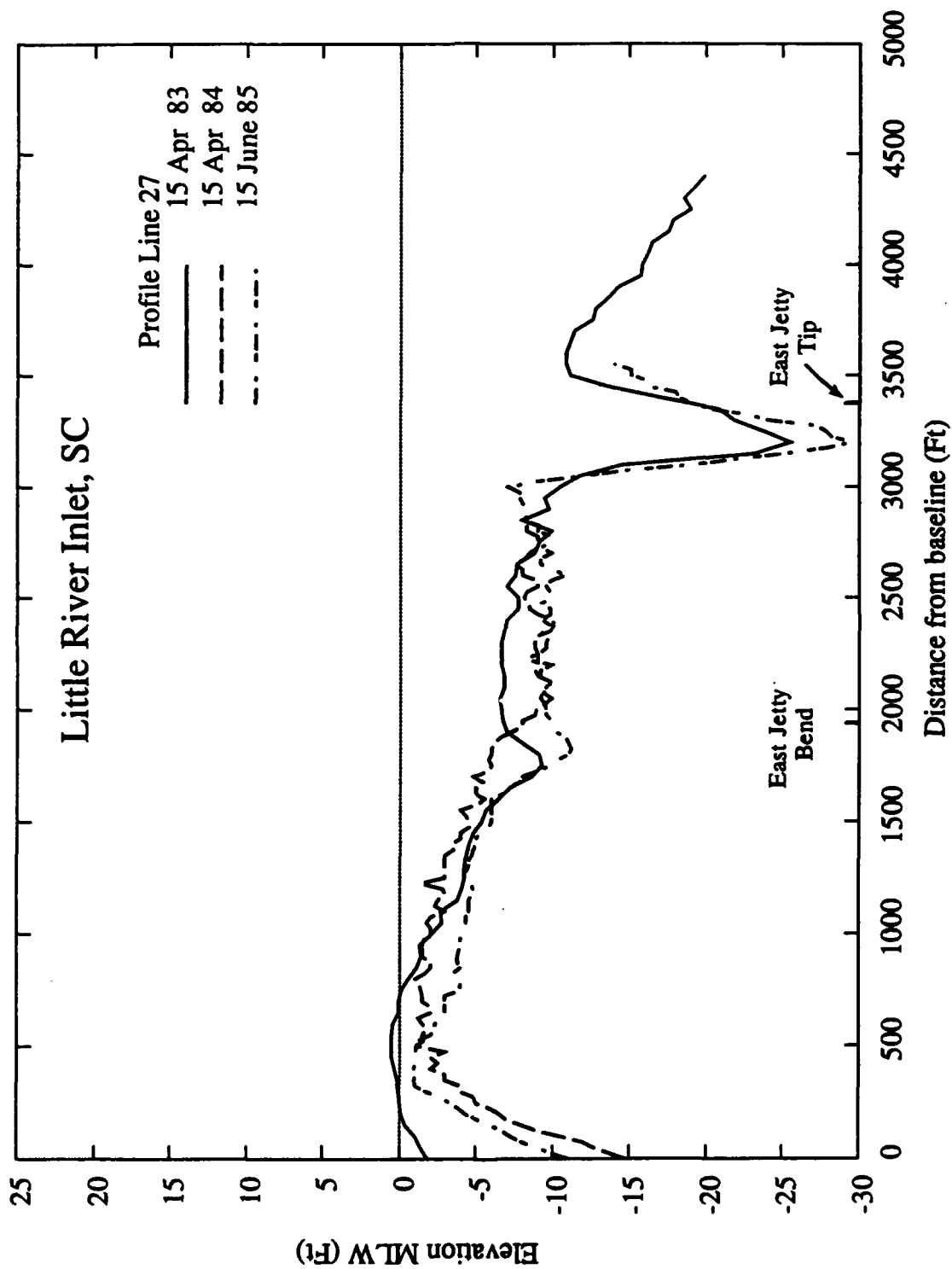


Figure 59. Profile along inside of east jetty: April 1983 to June 1985

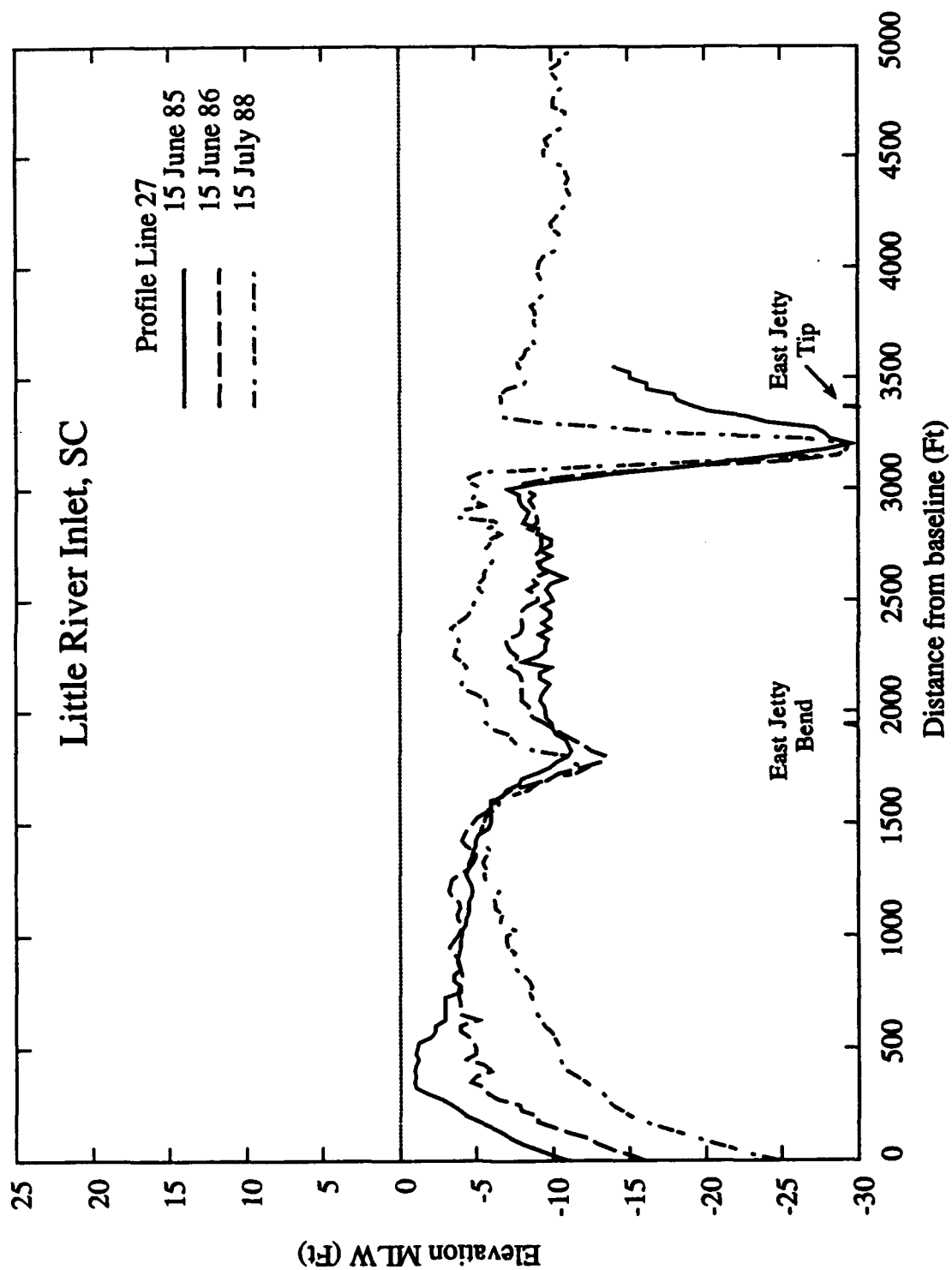


Figure 60. Profile along inside of east jetty: June 1985 to July 1988

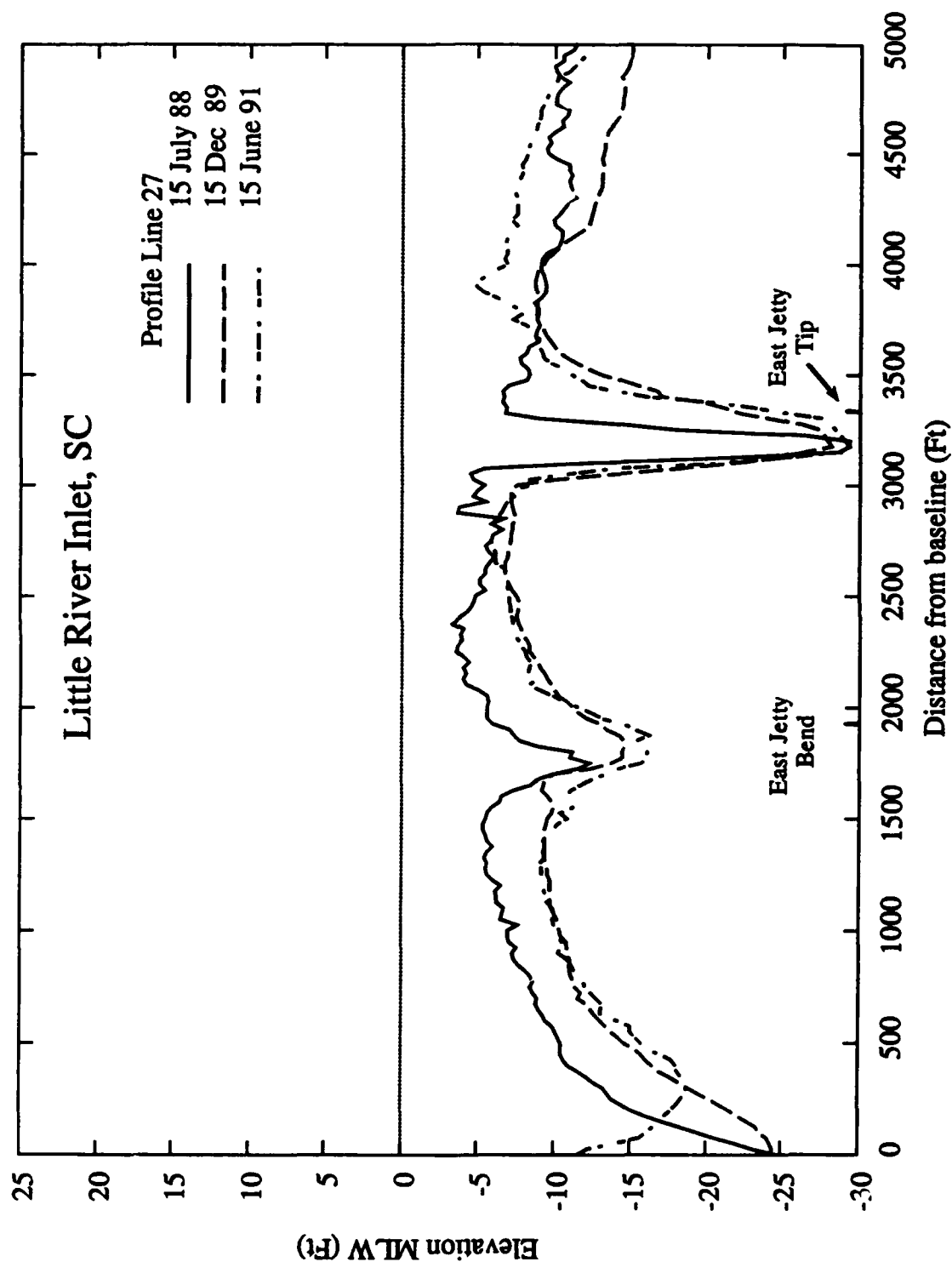


Figure 61. Profile along inside of east jetty: July 1988 to June 1991

jetty tip began around October 1982 and increased to depths greater than 25 ft MLW by April 1983 (Figure 58). A slight increase in depth also was evident at the east jetty bend. These deepening trends have continued (Figures 59 to 61). Note the increase in depths on the left side of Figures 59 and 60. The base point for Profile Line 27 lies within the naturally deep area (inlet gorge) described in Figure 4 and shows movement of that hole slightly seaward.

53. The area in the vicinity of the east jetty bend began to increase in depth more rapidly between the June 1990 and 1991 condition surveys (Figures 13 to 17, and 19). It appears that storm surge and wave action due to Hurricane Hugo in September 1989 may have expanded the area of and accelerated the deepening trend evident in this area prior to the storm. Additionally, the inlet-facing shoreline of Bird Island, which had accreted significantly since jetty construction, also began to erode significantly from November 1989 to the present (Figure 62). Visual observations made during the May 1991 field investigation indicated significant and active scarping of this shoreline, which lies adjacent to and drops off relatively steeply into the natural gorge area. Bird Island shoreline erosion is most likely due to deeper bathymetry near the east jetty bend, and movement of flow toward a more central location through the inlet (that is, closer to the east jetty and Bird Island).

54. A shoal has formed along the inside seaward portion of the east jetty (Figures 13 to 17, and 60). Initial accumulation of material in this area appears to be a function of ebb shoal morphology of the inlet at the time of jetty construction. Due to the dominant flow route being along the west jetty, the shoal along the east jetty has remained relatively stable, with some accumulation apparent in more recent surveys. Sediment eroding from the natural gorge area and the east jetty bend may also be a potential source of material for this shoal.

55. Scour at the tip of the east jetty is difficult to evaluate with available data. As discussed, physical model study observations suggest that the scour may be due to wave-generated longshore currents moving out parallel to the jetty, then combining with flood tidal currents. Also, currents during northeasters may flow parallel to the shoreline toward the jetty system and concentrate in the vicinity of the jetty tip. Bathymetric and profile surveys show that a portion of the ebb tidal delta is slowly rebuilding off

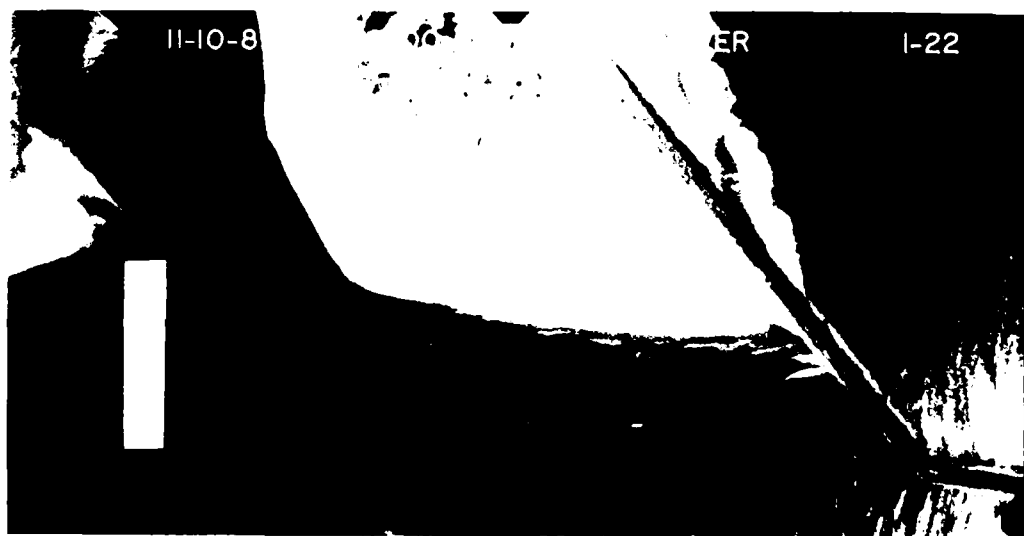


Figure 62. Aerial photography showing erosion of inside Bird Island shoreline

the tip of the east jetty and varies in depth between -5 and -12-ft MLW (Figures 61 and 63). The close proximity of the ebb shoal to the tip of the jetty also may be resulting in increased channelization of flood tidal flow through the scour hole.

Channel Dynamics

56. The deeper waters and subsequent scour which exist along the west jetty have been described in a previous section as a function of the historical thalweg position at the time of project construction (Figure 50). Since the jetties were completed, the channel thalweg has typically run north of the authorized channel in the upper reaches, swinging through the deep hole located at the bifurcation point of the main channel, then flowing back across the inlet and along the west jetty. It appears; however, in more recent condition surveys (1990 to 1991), that certain hydrodynamic and bathymetric conditions are undergoing changes in the inlet. These changes may have been accelerated by the occurrence of Hurricane Hugo in September 1989.

57. Results of this analysis indicate that the channel may be attempting to adjust to a more centralized location between the jetties; that is, the inlet cross-section is increasing and flow is distributing more uniformly across the inlet. The following is a summary of hydrodynamic and bathymetric conditions indicating this phenomenon:

- a. Results of the May 1991 field study show that the strongest tidal currents are not concentrated through the scour area along the west jetty as might be expected. Ebb and flood tidal current velocities were significant at all three locations (Stations 1, 2, and 3) monitored across the inlet (Figures 23 to 35). Maximum velocities were measured at Station 2 of about 4 ft/s on the ebb tide and 3.6 ft/s on the flood tide.
- b. Horizontal currents also were measured through the scour hole at the west jetty bend (Station 4) and the deep hole at the confluence of the bifurcated channel (Station 5). Tidal flow at Station 4 reached maximum velocities of only about 2 ft/s on the ebb and 1.5 ft/s on the flood tide (Figure 35). Ebb tidal flow was significant at Station 5 (Figures 23, 29 to 31, and 36), reaching maximum velocities of 3 to 3.5 ft/s. Flood velocities at Station 5, however, were not as strong, reaching maximum velocities of approximately 1.5 to 2 ft/s.

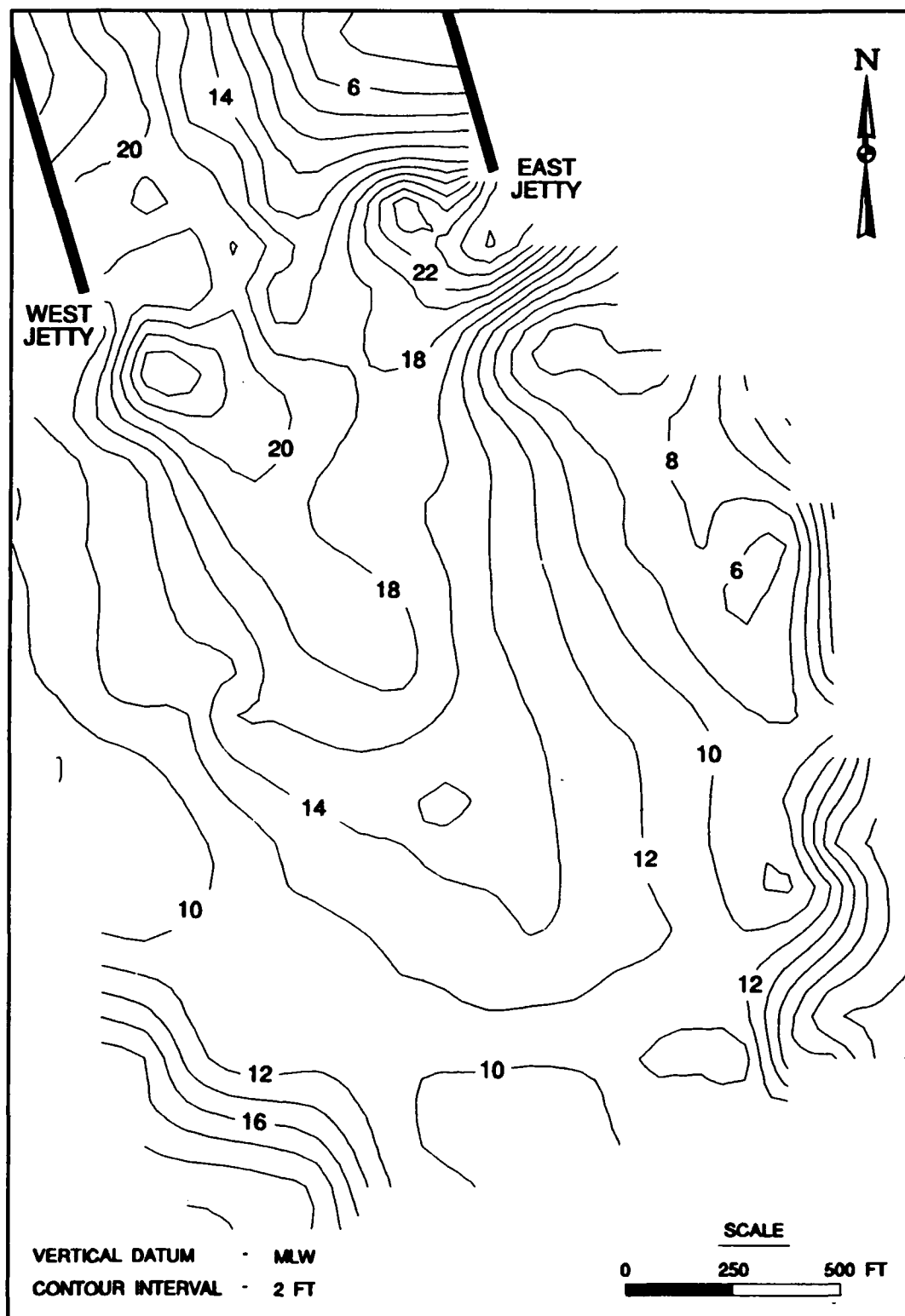


Figure 63. Ebb shoal morphology: July 1988

- c. Continued deepening of the area around the east jetty bend and erosion of the Bird Island shoreline indicates that tidal flow and currents are increasing in this area, potentially shifting some of the flow away from the west jetty.
- d. A rough cross-sectional slope analysis on a portion of the channel shows that the cross-channel slope is beginning to change and appears to be flattening across the inlet, thus becoming less steep towards the west jetty (Figure 64). The cross-sectional area analysis presented in Table 2 and Figure 20 also indicates that the inlet cross-section in that particular location is increasing, especially since the post-Hugo survey. These increases in area are relatively small; however, they do indicate that the inlet has not yet reached a long-term equilibrium condition.
- e. Recent condition surveys (Figures 13 to 17, and 19) showed some accretion of material along the west jetty since the post-Hurricane Hugo survey, and have not indicated increased scour along the structure.
- f. The east interior channel around the central flood shoal has gradually accreted since jetty construction, as the Bird Island shoreline and shoal morphology in its vicinity has changed. This smaller interior channel is subsequently not causing as much of a deflection of the main channel flow towards the west jetty.
- g. The physical model study's base condition (1974) had a main channel with a southeasterly orientation, while the initial prototype construction condition had a channel oriented toward the southwest. This difference would seem to make it difficult for the model to have predicted scour along the west jetty. It appears that the model was good at predicting the long term evolution, which indicated flows fairly centralized with a slight distribution of flow toward the east side of the channel region between the jetties. Prototype velocities measured in 1991 compared directly with model measurements at the scour region along the west jetty. This would indicate that flow distribution now occurring between the jetties in the prototype is similar to that which was seen in the model study, and would indicate a shift in flow distribution to a more centralized location between the jetties.

58. The volume of flow along the west jetty may be reduced as it begins to distribute more uniformly across the channel. The channel along the west jetty will probably not infill significantly as a result of the hydrodynamic changes, although some accretion of channel sediments may begin to occur on the Waties Island shoreline landward of the west jetty bend. Scour along the east jetty cannot be estimated at this time, but it should not be a significant problem if the tidal prism remains relatively stable.

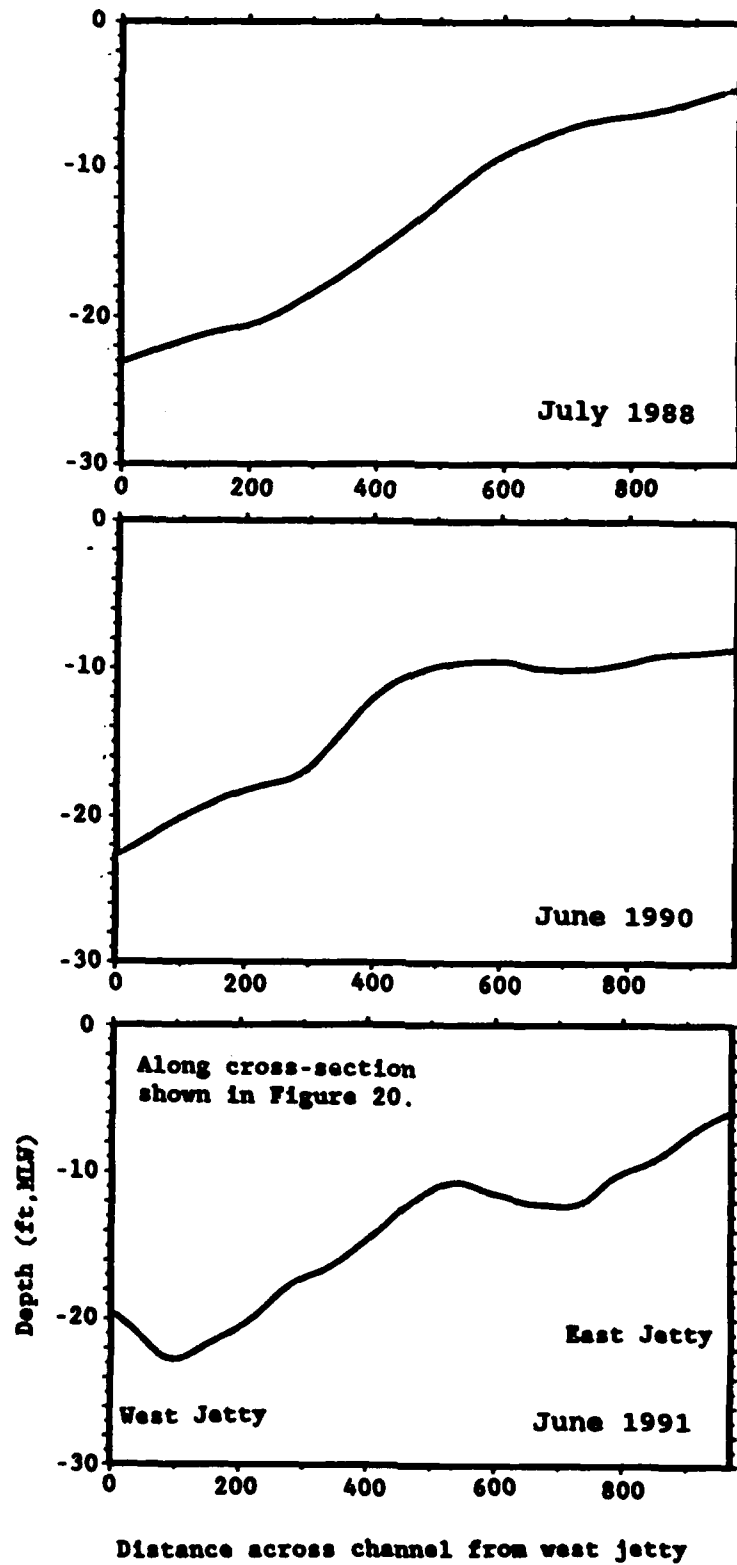


Figure 64. Inlet cross sections between jetties:
July 1988 to June 1991

PART V: CONCLUSIONS AND RECOMMENDATIONS

59. Although the inlet has not been dredged since December 1983/January 1984, the project depth of 12 ft MLW presently exists along a major part of the authorized channel (Figure 65) and navigable depths through the inlet are adequate. However, since project construction, the inlet channel has migrated and meandered from the authorized channel and the deepest waters exist immediately adjacent to the west jetty.

60. Channel migration and scour at both jetties began to occur immediately after construction and continued gradually over the period between 1981 and 1989. Since 1989, the inlet appeared to undergo additional changes, which may have been accelerated by Hurricane Hugo. Continued deepening around the east jetty bend and measured current velocities and patterns indicate that channel flow may adjust to a more centralized location between the jetties. These bathymetric and hydrodynamic changes may eventually establish a dynamic equilibrium within the inlet and alleviate scour along the west jetty.

61. Scour hole depths are increasing steadily at both jetty tips and may eventually result in damage to the structure heads. This analysis has concluded that the rate of scour along the west jetty has decreased; however, continued detailed monitoring by the Charleston District of the structure's stability is recommended.

62. Since navigable depths through Little River Inlet are adequate, it is recommended that no dredging operations be conducted at this time. The effects of a dredging operation may disturb the inlet's natural trend toward dynamic equilibrium and may even cause negative impacts along the east jetty. Once the channel has reached an equilibrium location, dredging should follow the natural thalweg and not attempt to realign the channel with the authorized project channel, unless navigation safety can no longer be assured. Chasten (1992) provides recommended alternatives for management of dredged material.

63. Continued monitoring of the Little River Inlet navigation project is essential for documentation of long-term trends. Bathymetric condition surveys of the channel and shoal areas should be conducted at least once a year. The surveys should cover an area from the northern portion of the central flood shoal (including portions of the bifurcated main channel and the deep hole at the confluence), through the jetties, and extend out to cover the

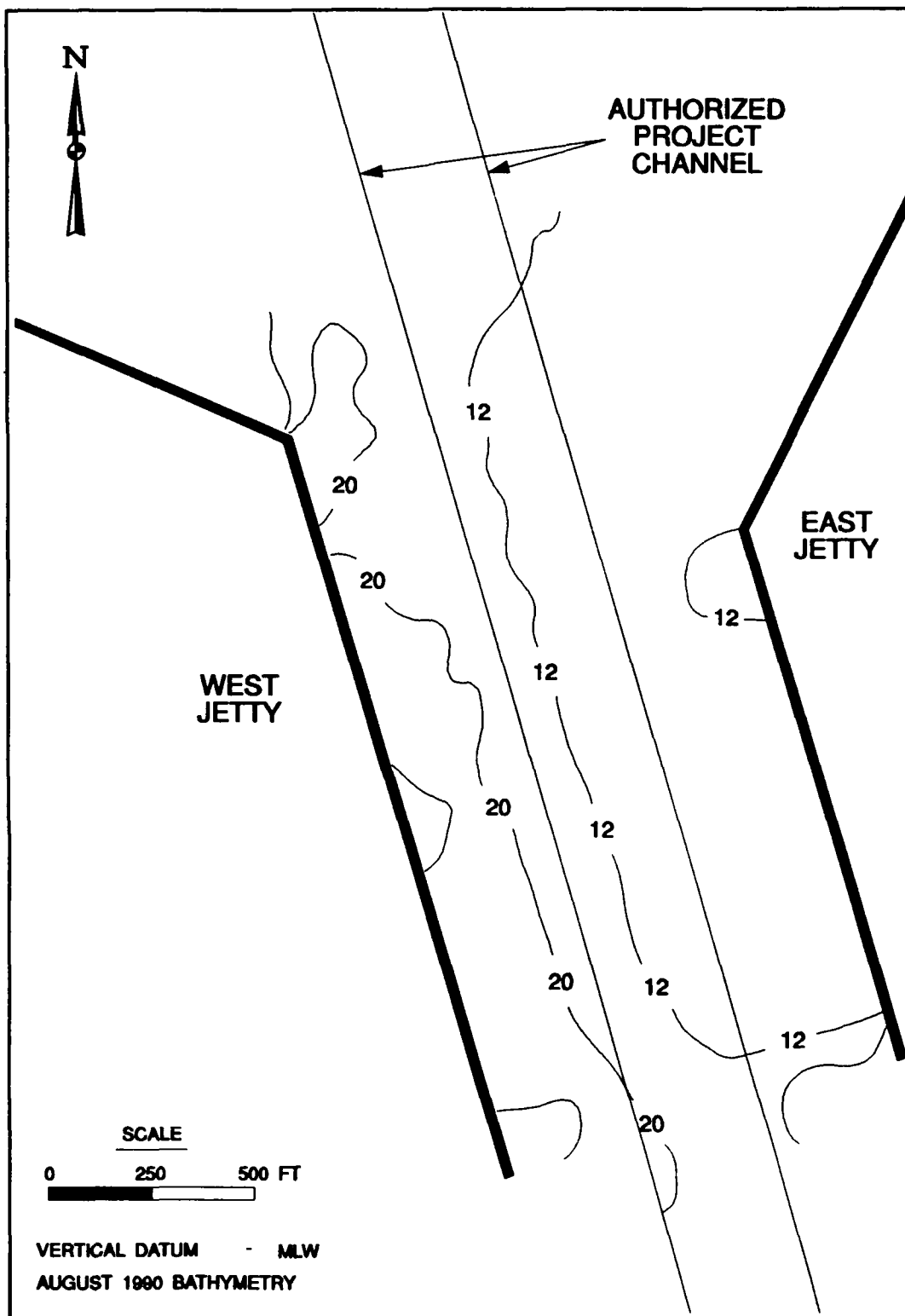


Figure 65. Authorized project channel and relative depths:
August 1990

ebb tidal delta (an area approximately 2,000 ft seaward from the jetty tips and 1000 ft east and west of the channel center line). Coverage of the ebb tidal delta is imperative in order to continue evaluating long-term channel and adjacent shoreline trends.

64. Continued analysis of the profile and bathymetric surveys should carefully examine changes occurring in the entire inlet system. Areas requiring particular attention include scour depths along the west jetty and at the jetty tips, deepening trends at the east and west jetty bends, shoreline trends on the inlet shoreline of Bird Island, movement or changes of the naturally deep "gorge" area, changes in the shoal just inside of the east jetty, and changes in the ebb tidal delta morphology.

65. Little River Inlet has not yet reached a long-term equilibrium condition. Results from future monitoring surveys should be used in conjunction with results from this study to interpret continued evolution of the inlet system.

REFERENCES

- Birkemeier, W. 1984. "A User's Guide to ISRP: The Interactive Survey Reduction Program," Instruction Report CERC-84-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Brown, P. J. 1977. "Variations in South Carolina Coastal Morphology" in Beaches and Barriers of the Central South Carolina Coast, D. Nummedal (ed).
- Chasten, M. A. 1992. "coastal Response to a Dual Jetty System at Little River Inlet, North and South Carolina," Miscellaneous Paper CERC-92-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Davies, J. L. 1964. "A Morphogenic Approach to World Shorelines," Zeit. fur Geomorph., Vol. 8, pp. 127-142.
- Davis, R. A. Jr., and Hayes, M. O. 1984. "What is a Wave Dominated Coast?" In: Hydrodynamics and Sedimentation in Wave Dominated Coastal Environments, B. Greenwood and R. A. Davis, eds., Vol 60.
- Hubbard, D. K., Oertel, G., and Nummedal, D. 1979. "The Role of Waves and Tidal Currents in the Development of Tidal Inlet Sedimentary Structures and Sand Body Geometry: Examples for North Carolina, South Carolina, and Georgia," Journal of Sedimentary Petrology, 49:1073-1092.
- InterOcean Systems, Inc. 1987. S-4 Current Meter User's Manual, San Diego, CA.
- Jensen, R. E. 1983. "Atlantic Coast Hindcast, Shallow Water, Significant Wave Information," WIS Report 9, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Kjerve, B., Shao, C. C., and Staper, F. W., Jr. 1979. "Formation of Deep Scour Holes at the Junction of Tidal Creeks: An Hypothesis," Marine Geology, Vol. 33.
- National Oceanic and Atmospheric Administration, National Ocean Service 1991. Tide Tables 1991. East Coast of North and South America including Greenland, Rockville, MD.
- Price, W. A. 1963. "Patterns of Flow and Channeling in Tidal Inlets," Journal of Sedimentary Petrology, Vol. 33, No. 2.
- Seabergh, W. C., and Lane, E. F. 1977. "Improvements for Little River Inlet, South Carolina," Technical Report H-77-21, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- US Army Engineer District, Charleston. 1971. Little River Inlet Brunswick County, North Carolina and Horry County, South Carolina. Survey Report on Navigation, Charleston, SC.
- _____. 1977. Little River Inlet North Carolina and South Carolina Navigation Project. General Design Memorandum, Charleston, SC.

_____. 1990 (Mar). Little River Inlet Navigation Project. Little River Inlet, North and South Carolina. Letter Report of Post-Hugo Damage Assessment. Charleston, SC.

Ward, D. L., and Knowles, S. C. 1987. "Coastal Response to Weir Jetty Construction at Little River Inlet, North and South Carolina," Coastal Sediments '87. American Society of Civil Engineers.

APPENDIX A: SIDE-SCAN SONAR SURVEY AND DATA INTERPRETATION

1. This appendix contains information on the side-scan sonar survey which was conducted at Little River Inlet on 23 May 1991. The focus of this data collection program was the inside, or channel side, of the west jetty. Data obtained from the operation is limited due to side-scan methods and equipment used. However, general observations were developed from the data as to the condition of the west jetty and are provided herein. The May 1991 side-scan survey also was compared with a post-Hurricane Hugo side-scan survey obtained by the Charleston District in 1989.

Side-Scan Sonar Operation

2. For this study a dual-channel, dual-frequency side-scan sonar image system was utilized. The Charleston District of the US Army Corps of Engineers provided a Klein Model "Hydroscan" side-scan sonar system and the technical support required to run it. This system can be operated at either 100 or 500 kHz. The system transmits two simultaneous "fan-shaped" beams to the sides of the tow-fish axis. Transmitted signals reflect from bottom features that have relief. Reflected signals are received by transducers in the tow-fish, and are filtered, amplified, and displayed on paper. The paper analog acoustic image is similar in appearance to an oblique "aerial" photograph of the jetty structure. The gross condition of the jetty and the occurrence of bedforms or foreign objects in the vicinity of the structure can be discerned from these data.

3. The limited depth of the channel and the anticipated high volume of traffic running the inlet prior to a holiday weekend required that the side-scan fish be kept close to the boat. The side-scan tow-fish was slung along the starboard forward portion of a 22-ft, outboard, open cockpit fiberglass boat. The tow-fish depth was limited to 3 ft to maximize the slant range while still protecting it from emergence caused by the wakes of passing boats or breaking waves.

4. The side-scan records were collected over a period of 3 hr, during slack tide on Thursday morning, the 23rd of May, 1991. Data quality was somewhat compromised by the limited amount of time available for operation and the age and condition of the system used for data acquisition.

5. Four runs were made in an attempt to ensure collection of the best possible data. Data from the multiple runs were repeatable and confirmed that the system was operating. During Run 4, the survey vessel maneuvered around a small occupied fishing boat. The hull and outboard motor of this boat appeared clearly on the side-scan image.

6. A side-scan run consisted of running the boat at a constant speed, 75 to 150 ft off the jetty structure. The vessel operator attempted to maintain a straight course for the duration of the data recording process. During the run, marks were generated on the records to indicate known positions along the jetty. Marks were largely limited to the beginning of the jetty, the landward break in the jetty structure angle (the dogleg) and a mark (#3) painted on the jetty structure. Positioning of the boat during data acquisition was largely uncontrolled. As such, the interpreted data should be considered reconnaissance level and should not be used to make engineering decisions.

Data Interpretation

7. Due to limitations imposed by the positioning technique, the following interpretation methods were utilized. The length of the straight portion of the west jetty seaward of the "dog-leg" was estimated to be approximately 3,450 ft. Using this estimate, the jetty was partitioned into approximately 85-ft segments, with 0 being the seaward tip of the structure. This method compensated somewhat for the lack of positioning, and facilitated intercomparison of acoustic shadows observed on different runs. In the event that the length estimation is grossly inaccurate, ranges labeled on the records would simply require scaling to correct the error. Table A-1 contains details of interpretation for each individual run. The observations made of these four runs then were compared to construct an overall side scan interpretation.

Summary of Side-Scan Interpretation

8. 0 - 165 ft: There is a noticeable increase in depth toward the seaward tip of the jetty. This deepening trend also is noted in the post-Hugo side-scan records. Landward, sand shoals appear against the lower jetty flanks.

9. 165 - 1,395 ft: The jetty structure appears to be intact (Figure A1). There is minimal debris or dislodged rock at the jetty/sediment interface. Low amplitude, long wavelength bedforms are probably present. Water depth increases between jetty mark 165 and 1,395 ft.

10. 1,395 - 1,970 ft: The jetty structure appears to be most exposed at this reach. The deepening trend has stopped and the bottom appears to be horizontal. Linearity of the sediment/jetty structure interface suggests there is no debris or dislodged rocks in this region.

11. 1,970 - 2,625 ft: The image of the jetty structure is not as sharp as it was seaward of 1,970 ft. It is possible that some of the jetty rocks are either partially buried by sand or displaced. Side-scan records show a low, long shoal flanking the jetty.

12. 2,625 - 3,280 ft: In this stretch, the irregular imagery suggests stone, or sand partially burying some portions of the structure. On records from Run 4, two objects that may be as large as 3 ft across appear at the base of the jetty. Small flood-oriented sandwaves are ubiquitous in this region.

13. 3,280 ft: The jetty region landward of the dogleg was not evaluated during this survey. The region was shoaled and considered too hazardous to survey.

May 1991 and Post-Hugo '89 Data Comparison

14. In both the May 1991 and post-Hugo 1989 data sets, it is clear that the channel side of the west jetty is shoaled on its landward reach. The post-Hugo data set shows the shoaled condition of the jetty very clearly. Further, the scoured condition at the seaward tip of the jetty had not improved since 1989.

15. The seaward half of the jetty between the scour hole and the shoaled jetty flanks contains a bedform field. Depth of the bedforms increases slightly to the middle of the inner jetty, where it stabilizes. The presence of scour along the seaward half of the west jetty could not be confirmed by this data set. If scouring is present it would probably be located in the area between 1,395 and 1,970 ft, noted on Run 2.

16. An inspection of irregularities identified in the area around the jetty dogleg will confirm the presence or absence of loose jetty debris. Two objects appear at the jetty base in Run 4 at 3,035 and 3,120 ft.

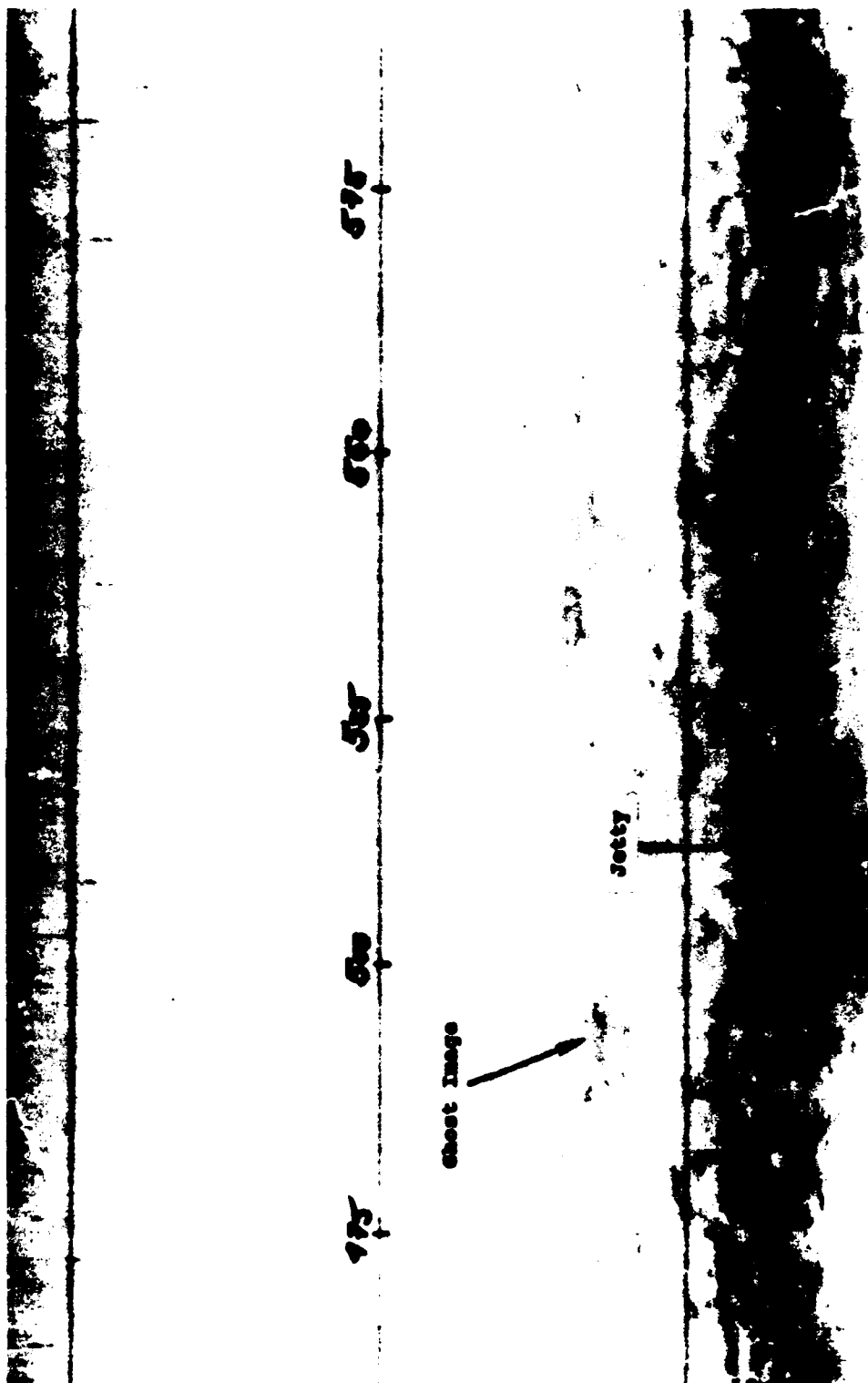


Figure A1. Side-scan sonar survey showing example of jetty in good condition, Run No. 2, 24 May 1991

Table A-1
Side-Scan Data Interpretation

Location: Little River Inlet, South Carolina
 Run: 1
 Target: West Jetty, Channel Side Structure
 Frequency: 100 kHz
 Range: 250 ft

Overall records are of low, but usable quality

0 - 165 ft	Scour noted at the seaward tip of jetty rock structure difficult to evaluate.
165 - 1,560 ft	Rock structure appears to be sound. Image of marginal quality. Bedforms not discernable, may or may not be present.
1560 - 2,050 ft	Jetty flank slope appears to be spread out, possible displacement of jetty stone. Sandwave/shoal may be burying jetty flanks. Shoal seen in bathymetric portion of records.
2050 - 2,955 ft	Upper portion of jetty appears in good shape. Lower apron of structure may have displaced stone. Debris noted at the sediment/jetty interface. Jetty flanks shoaled by sand.
2955 ft +	Records are of poor quality and cannot be interpreted.

Location: Little River Inlet, South Carolina
 Run: 2
 Target: West Jetty, Channel Side Structure
 Frequency: 100 kHz
 Range: 250 ft

0 - 85 ft	Slight scour apparent at jetty tip. Bedforms, low amplitude, long wave length. Probably of medium sandwave classification. Symmetry of bedforms not obvious.
85 - 1,395 ft	Jetty slope appears to be sound. Debris or fallen stone not apparent at jetty base. Sediment/jetty interface is linear, suggesting no build-up of sand shoals. Low amplitude oscillatory (symmetrical) bedforms.
1395 - 1,970 ft	Jetty slope intact. Dark acoustic image suggests steep jetty flanks. Bedforms minimized, possible scour area. Area of increased velocities. Looking at the bathymetric portion of the side-scan data, channel deepens from jetty tip to 1,395 ft, then levels and maintains depth to 1,970 ft.
1970 - 2,870 ft	Irregular sediment/jetty interface. Image suggests that a sand shoal is building against the jetty flank. Bedforms are present, low amplitude, long wavelength, asymmetrical, ebb and flood oriented.
2870 - 3,280 ft	Jetty slope appears intact. Possible sand build-up on jetty flanks.

Location: Little River Inlet, South Carolina
Run: 3
Target: West Jetty, Channel Side Structure
Frequency: 100 kHz
Range: 250 ft

Overall records are of low, but usable quality

0 - 85 ft	Scour noted at the jetty tip. Bathymetry deepens noticeably as the seaward end of the jetty is approached.
85 - 265 ft	Side-scan data are of poor quality. Possible rubble at the jetty base, unconfirmed. Bedforms may be present.
265 - 755 ft	Jetty image is faded. Jetty/sediment interface is flat and regular. Linearity of this contact suggests that the jetty is in good shape, no stones appear to be displaced. Channel depth is increasing slightly landward.
755 - 1,640 ft	Jetty image is improved. Jetty structure appears to be intact. Loose stone are not evident. Bedforms are observed at the jetty/sediment interface. Sandwaves appear to be flood oriented.
1,640 - 2,050 ft	Jetty image is excellent. Bedforms are not observed. This is the deepest region of the jetty flank. Maximum exposure of the jetty slope. Wake from passing boat imprinted on records.
2,050 - 2,300 ft	Jetty image is bleached on the records. Possible sandwave encroaching on jetty flanks.
2,300 - 2,545 ft	Improved jetty image. Slight deepening of channel. Flood oriented bedforms noted.
2,545 - 3,200 ft	Jetty image is poor. Possible encroachment by sand shoals. Shoaling indicated by bathy portion of records. Some debris, possible loose stone at jetty/sediment interface. Bedforms appear symmetrical to flood oriented.
3,200 ft +	Past the "dogleg" records deteriorate. Analysis not possible.

Location: Little River Inlet, South Carolina
Run: 4
Target: West Jetty, Channel Side Structure
Frequency: 100 kHz
Range: 250 ft

Jetty Image is faint, bedforms/bathymetry are clear

- 0 - 85 ft Scour at jetty tip is apparent. Bedforms are present.
 - 85 - 740 ft Large wavelength sandwave. Shoal probably buries the jetty apron.
 - 740 - 1,970 ft Jetty image is of poor quality. Bathymetry is level, constant. Bedforms are present. Jetty is exposed and appears structurally sound between 1,640 and 1,970 ft.
 - 1,970 - 2,545 ft Jetty image is poor. Low amplitude, large wavelength shoal against the jetty.
 - 2,545 - 3,450 ft Jetty flanks buried by shoal. Two objects appear at jetty base at 3,035 and 3,120 ft. Flood oriented bedforms are ubiquitous in this stretch.
 - 3,450 - 3,775 ft Image of fishing boat w/outboard motor (on surface) is evidence of working state of SSS system, indicates good image
-

Location: Little River Inlet, South Carolina
Run: Post Hugo records, December 1989
Target: West Jetty, Channel Side Structure
Frequency: 100 kHz
Range: 495 ft

The 1989, post Hugo records were run at a range of 495 ft. The recorder was also set to a slower speed. The side-scan records are compressed compared to the newer records.

- 0 - 295 ft Scour is evident at the seaward jetty tip. Jetty appears structurally sound.
 - 295 - 1,180 ft Excellent jetty image. Jetty flanks are exposed, suggests scour at jetty/sediment interface. Some bedforms are present, details are masked by scale of records. At 590 - 1,180 ft bed appears flattened, possibly post Hugo planed beds.
 - 1,180 - 1,770 ft Jetty image is good, structure appears sound. Jetty flanks buried by sand shoal. Bedforms are evident on the side scan records (Figure A2).
 - 1,770 - 2,365 ft Jetty flanks encroached by sand wave. Flood oriented sand wave burying jetty base. Small sand waves superimposed on larger one. Jetty rubble, stone exposed on back side of the large bedforms.
 - 2,365 - 2,660 ft Trough side of seaward, flood-oriented sand wave.
 - 2,660 - 3,250 ft Flood-oriented bedforms burying the jetty flanks.
-

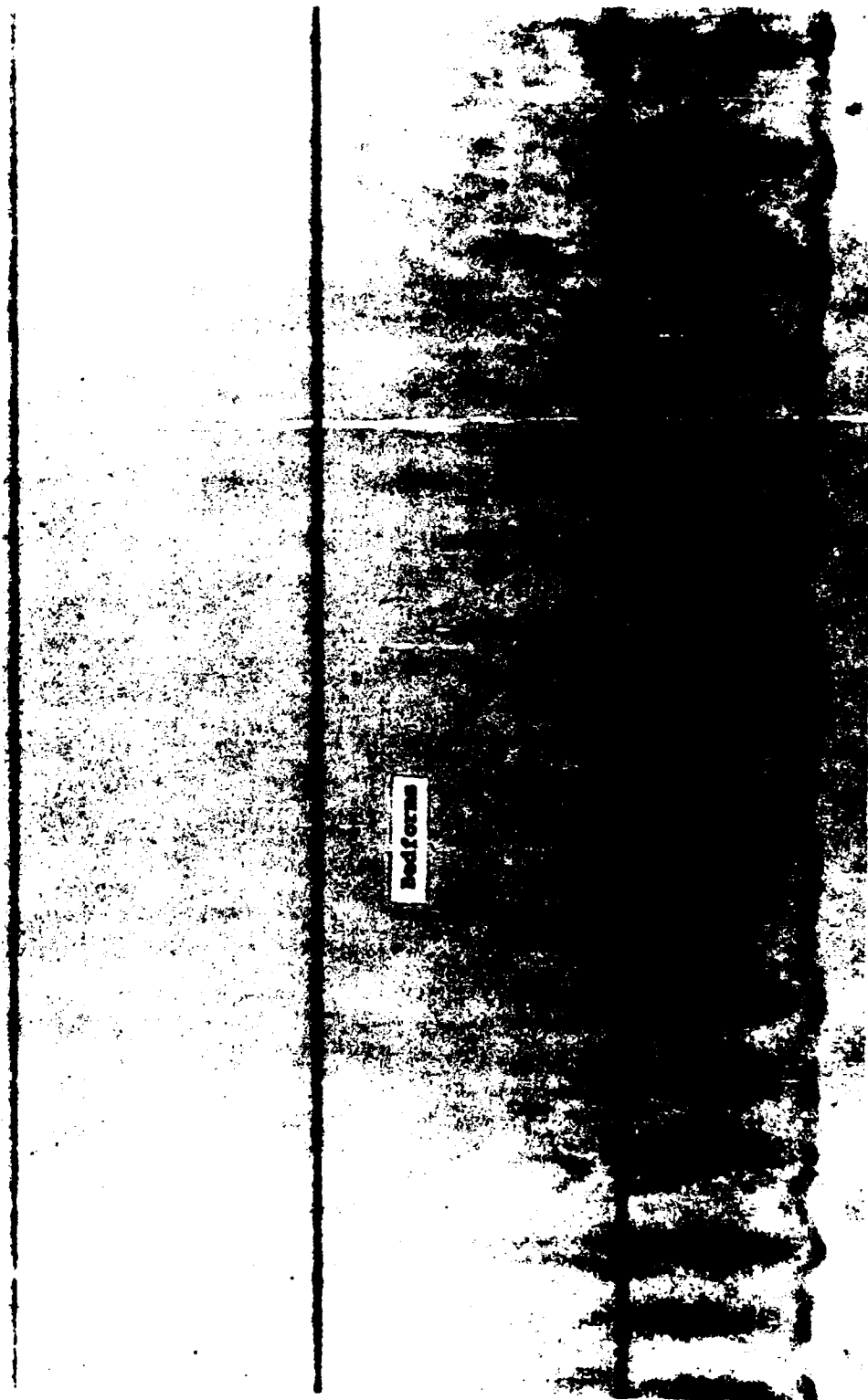


Figure A2. Side-scan sonar survey showing example of bedforms, Run No. 4, 24 May 1991

Waterways Experiment Station Cataloging-In-Publication Data

Chasten, Monica A.

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